CONF-980653--Absts.

Abstracts of the Third International Conference on the *Solid State Lasers for Application to Inertial Confinement Fusion*

Sponsors:

Lawrence Livermore National Laboratory

Commissariat à l'Energie Atomique

June 7-12, 1998 • Monterey, California

Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

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W. H. Lowdermilk
(Technical Coordinator)

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Color separation grating designs for the National Ignition Facility

S. N. Dixit and J. Sanchez

Lawrence Livermore National Laboratory
L-493, P. O. Box 5508, Livermore, California 94551

Tel: (925) 423-7321 FAX: (925) 422-5537 E-mail: dixit1@llnl.gov

Current NIF baseline employs a color separation grating (CSG) for diverting the unconverted light away from the ICF target. The NIF CSG consists of a three level lamellar grating structure which diverts nearly all of the unconverted 1w and 2w light while leaving the 3w light undiffracted. Nearly 84% of the diffracted light is contained in two orders (-1 and +2 for example) with the remaining energy distributed in several higher orders. The direction of the diffraction can be rotated by changing the orientation on the CSG on the optic. From fabrication considerations, it is preferable to have a minimal number of different CSG orientations. At the same time, it is important to ensure that the diffracted light is not hitting the target insertion module and the various diagnostic ports near the target chamber center and is prevented from entering other laser ports. For some users on NIF it is also desirable to provide a fairly large (several cm long) gap near the hohlraum.

We have developed a computer model to analyze and display the location of the various diffracted orders in the NIF target chamber. The code generates the intensity distribution in a user prescribed volume from all the 192 NIF beams. Arbitrary CSG periods and grating orientations can be selected externally.

Using this computer code, we are developing CSG layouts for all the 192 NIF beams which satisfy the constraints regarding the distribution of the unconverted light near the target chamber center. Preliminary designs indicate that only a few CSG orientations may be sufficient to satisfy all the requirements. Detailed results will be presented.

This work was performed under the auspices of the U. S. Department of Energy by the Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

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Fabrication of large aperture color separation grating for Beamlet laser

S. N. Dixit, L. Auyang, J. Britten, T. Parham, M. Rushford and L. Summers

Lawrence Livermore National Laboratory
L-493, P. O. Box 5508, Livermore, California 94551

Tel: (925) 423-7321 FAX: (925) 422-5537 E-mail: dixit1@llnl.gov

Current National Ignition Facility (NIF) baseline design employs a color separation grating (CSG) for diverting the unconverted light away from the ICF target. CSG consists of a three level lamellar grating structure designed so that nearly all of the 3ω light passes through undiffracted while the unconverted 1ω and 2ω light is diffracted away from the target. Considerations such as the mask and overlay precision, etch depth control etc. place limitations on the actual performance of a CSG.

We have recently fabricated a full aperture (40-cm square) color separation grating in fused silica for use on the Beamlet laser. This CSG had a period of 345 μm and was fabricated using a two mask lithography process with wet etching. Off-line measurements of the 1ω and 2ω transmission indicate that less than 1% of the light at these wavelengths is remaining in the zeroth order. The 3ω transmission in the zeroth order for an non-anti-reflection coated substrate is 89% which compares well with the transmission of an uncoated fused silica flat (92.5%). We are currently examining the anti-reflection coated CSG performance. Results will be reported along with its performance on the Beamlet laser.

This work was performed under the auspices of the U. S. Department of Energy by the Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

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TP

EXPERIMENTAL AND CALCULATIONAL INVESTIGATION OF THE OUTPUT PULSE TEMPORAL PROFILING METHOD CONSISTING IN TEMPORAL SHIFTS OF PULSES FROM VARIOUS PARTS OF APERTURE

Eroshenko Victor A., Annenkov Vladimir I., Solomatin Igor I., Chebotar Victor S.

Russian Federal Nuclear Center - Institute of Experimental Physics (VNIIEF)
37, pr.Mira, Sarov, Nizhni Novgorod region, Russia, 607190
Phone: (831-30)-4-56-46, Fax: (831-30)-5-45-65,
E-mail: SUKHAREV@otd.13.vniief.ru

Experimentally and calculationaly the possibilities and problems are analysed of the high-power laser output pulse temporal profiling method which consists in relative temporal shifts of separate parts of beam aperture. Beam splitting is made at the early stages of pulse amplification. The effects of subsequent amplification and spatial filtration are investigated.

15-A
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COMPUTER MODELING OF OUTPUT AMPLIFIER MODULE PUMPING OF "LUCH" FACILITY AND SHORT PULSE AMPLIFICATION

Eroshenko Victor.A., Garanin Sergey.G., Kirillov Gennada.A.,
Kochemasov Ggennady.G., Krotov Valery.A., Sukharev Stanislav.A.

Russian Federal Nuclear Center - Institute of Experimental Physics (VNIIEF)
37, pr. Mira, Sarov, Nizhni Novgorod region, Russia, 607190
Phone: (831-30) 4-56-46, Fax: (831-30) 5-45-65, E-mail: SUKHAREV@otd.13.vniief.ru

Results of computer modeling by Monte-Carlo method of "Luch" facility amplifier module pumping are reported, as well as results of short pulse amplification calculations in the four-pass output amplifier cascade of this facility. The aim of amplification calculation was amplifier configuration optimization and investigation of the degree of nonlinear pulse distortions during amplification.

017
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THE MÉGAJOULES FRONT-END LASER SYSTEM OVERVIEW

Philippe Estraillier, Hélène Ferrand, Alain Jolly, Philippe Kramer,
Jacques Luce, Claude Rouyer

Commissariat à l'Energie Atomique
BP 02 33114 LE BARP
FRANCE

The Mégajoules laser (LMJ) consists of a 240 beam high-energy glass laser system and target chamber. Each beam originates from the Front-End as a nominal 1 joule, 20 ns pulse, at 1053 nm. Advances in microchip lasers, temporal modulation, diode-pumped rod amplifiers and spatial beam shaping are required to generate the laser pulse for LMJ. Those technologies will be qualified and improved on a full scale 8 beam laser, Ligne d'Intégration Laser (LIL), whole assembling will start in June 98.

In this paper, we present an overview of the Front-End laser system from the master oscillator to the injection into the transport spatial filter of the main laser amplifier.

Each beam originates in one of the 240 diode-pumped microchip lasers. The active medium is Nd:YLF crystal, and the output pulse is delivered in a single mode fiber.

Spectral and temporal intensity modulations are performed by integrated electro-optic modulators. A phase modulator produces a 0.1 nm chirp and an amplitude modulator controls the beam intensity.

The main amplification stages of the Front-End are in the preamplifier module (MPA) which is physically located under the transport spatial filter of the main LMJ beamline. A single mode fiber for each beam provides a 1 nanojoule temporally shaped pulse to each MPA, where the energy is boosted to 10 millijoules at 1 Hz in a diode-pumped regenerative amplifier, and to 1 joule in a four-pass amplifier. The regenerative amplifier is designed with an internal beam shaping, and a side-pumped square rod, in order to provide a flat top square output pulse. Then, the pulse is spatially shaped (to compensate for spatial gain variations in the main laser cavity) by using a spatial light modulator based upon the combination of an electrically addressable liquid crystal display projected onto an optically addressable liquid crystal cell. Finally, a four pass flashlamp-pumped rod amplifier boosts the square beam to approximately 1 joule (diode-pumping is also investigated as an alternative).

We will describe the Front-End laser system, and discuss experimental results to date on its components.

0-24
MP

HIGH THRESHOLD HfO_2/SiO_2 MIRRORS MADE BY SPUTTERING PROCESS

A. Fornier, D. Bernardino, O. Lam, J. Néauport
CEA - Centre d'Etudes de Limeil-Valenton
94195 Villeneuve Saint-Georges Cedex
- FRANCE -
Tel: 33 1 45 95 63 92 - Fax: 33 1 43 86 74 07

F. Dufour, B. Schmitt
SAGEM SA
Centre d'étude d'Argenteuil
72-74 rue de la Tour Billy
95101 Argenteuil Cedex
- FRANCE -
Tel: 33 1 34 26 38 00 - Fax: 33 1 34 26 37 12

J.M. Mackowski
Service des Matériaux Avancés
Institut de Physique Nucléaire de Lyon
43 Bd du 11 Novembre 1918
69622 Villeurbanne Cedex
- FRANCE -
Tel: 33 4 78 89 19 36

A major preoccupation, for the design of the LMJ laser, is the mirrors laser damage threshold. SAGEM SA, in collaboration with the CEA, has conducted a study in order to improve the laser induced damage threshold under operational conditions.

SAGEM SA demonstrated, in an earlier study, their ability to manufacture high damage threshold mirrors (> 50 J/cm^2). However, the damage threshold is reduced in the case of surface contamination.

A different high index material was proposed in order to improve the performances when there is surface contamination.

This study was done in the following 3 phases.

- implementation of the HfO_2 deposition process by ion beam sputtering and definition of the deposition conditions which are supposed to be the best adapted,
- realization of 25.4 mm diameter HfO_2/SiO_2 mirrors, the conditions of deposition for this mirrors having been deduced from the first phase of the study,
- realization of some mirrors with dimensions close to the actual operational dimensions (80 mm diameter).

At each phase of the study, the single layers and the mirrors were characterized:

- absorption mapping,
- diffusion mapping,
- spectrophotometric measurements on the monolayers,
- determination of the laser induced damage threshold,
- surface inspection by optical microscopy.

The damage thresholds obtained for 80 mm diameter mirrors are encouraging. The damage threshold for a contaminated surface is presently being evaluated.

Energy storage efficiency and small-signal gain measurement in Nd:Phosphate glass

C. Gamache[1], D. Descamps[2], D. Husson[1], O. Cabourdin[1], G. Letouzé[1], J.F. Mengué[1] and A. Migus[2].

1 Commissariat à l'Energie Atomique, Centre d'Etudes de Limeil-Valenton, 94195 Villeneuve St Georges, France.

Fax : 33 1 43 86 74 38, email : boschero@limeil.CEA.fr

2 Laboratoire pour l'Utilisation des Lasers Intenses, CNRS UMR 100 Ecole Polytechnique,

91128 Palaiseau, France.

Fax : 01 69 33 30 09

Summary :

The large laser facilities for ignition such as NIF or LMJ [1] rely on previous experimental and numerical studies on storage and gain capabilities. Neodymium doped-phosphate-glass has been chosen as the gain medium but, although it has been studied in great details for more than thirty years [2,3], we found it necessary to make absolute value spectroscopic measurements. These parameters are particularly needed as inputs in the modeling of the amplifying stages. To get a good understanding of Nd-doped-glasses on its energy storage processes and gain capability, we develop different experimental schemes based on amplifiers pumped by laser [4] and by flashlamps [5, 6]. In parallel, we have developed numerical models which simulate the exact geometrical configuration of the amplifiers. The main result of experiments is that the use of an adjustable parameter (or an arbitrary quantum yield) is always needed to obtain a good agreement between experimental and numerical results on gain measurements. Whatever method of pumping, we had

mechanisms correlated to spectroscopic properties of a high density of excited neodymium ions. These mechanisms are up-conversion [9] and Excited State Absorption (ESA) [10]. However part of the losses is also due to non spectroscopic factors such as the pumping geometry [8].

In a first serie of experiments on loss mechanisms (fig. 2), we created a calibrated population in the $^4F_{3/2}$ level by using a laser which longitudinally end-pumped Nd:phosphate LG760 amplifier and, we measured the gain for a broad-band chirped-pulse. By looking fluorescence of the higher level $^4G_{7/2}$ we clearly show that the $^4F_{3/2}$ excited state absorbs the laser radiation at 1.06 μm (fig. 1). To quantify these effects, we measured both the reduction of the effective lifetime of $^4F_{3/2}$ level due to up-conversion (fig. 3) and the double-pass small-signal gain as a function of pump fluence (fig. 4). The experimental set-up is similar to [4]. The calculation of the storage energy is obtained from the model developed in [4] completed with ESA at 1.06 μm. Taking into account the experimental value of the up-conversion rate [11], the measured small signal gain follows the theoretical predictions, using 1.06 μm ESA cross-section of $\sigma_{ESA} \approx 0.3\ 10^{-20}$ cm^2. This value, which corresponds to 7% of the emission cross-section, is in agreement with our previous measurement [7].

The second series of experiments deals with a configuration more relevant to the LMJ project, namely the flashlamp pumping of Nd:phosphate glass disk amplifier [12]. The measured single-pass small-signal-gain was compared to different sets of models. The first code developed by CEA and LLNL is a 2.5 D simulation of pumping. Agreement between theory and measurements is obtained when using a value of 0.8 for the adjustable yield parameter (fig. 5). A more recent preliminary work based on 3 D simulation including refraction effects on the pump light allowed to get agreement with a yield closer to unity [12]. However other parameters are now being examined such as a residual absoption of the pump wavelength by the host matrix.

The presentation will summarize the different demonstrated effects and their relative importance in the LMJ project as well as in future designs of solid-state lasers implying diode laser pumping.

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Figure captions :

Figure 1 : Time evolution of the green fluorescence without (fig. 1.a) and with (fig. 1.b) the 1.06 μm pulse (fig. 1.c).

Figure 2 : Energy level diagram of Nd^{3+} in glasses and illustration of the excited state absorption at 1.06 μm.

Figure 3 : Time evolution of pump intensity and of infrared fluorescence (1.06 μm) emitted from the excited state $^4F_{3/2}$ as a function of pump fluence.

figure 4 : Laser pumped Nd:phosphate LG760 rod amplifier. ● Experimental small signal double-pass gain measurements versus pump fluence (total extracted energy / 85 μJ input chirped pulse energy). The solid line is obtained when taking into account upconversion and ESA at pump and signal wavelength to calculate the gain. The dotted line is gain calculated without taking into account ESA signal.

figure 5 : Flashlamps pumped Nd:phosphate LG750 disk amplifier. ● Experimental small signal single-pass gain measurements versus pump fluence. The solid line is obtained when taking into a adjusted yield parameter of 0.79 to calculate the gain. The dotted line is gain calculated without taking into the quantum yield.

Figure 1

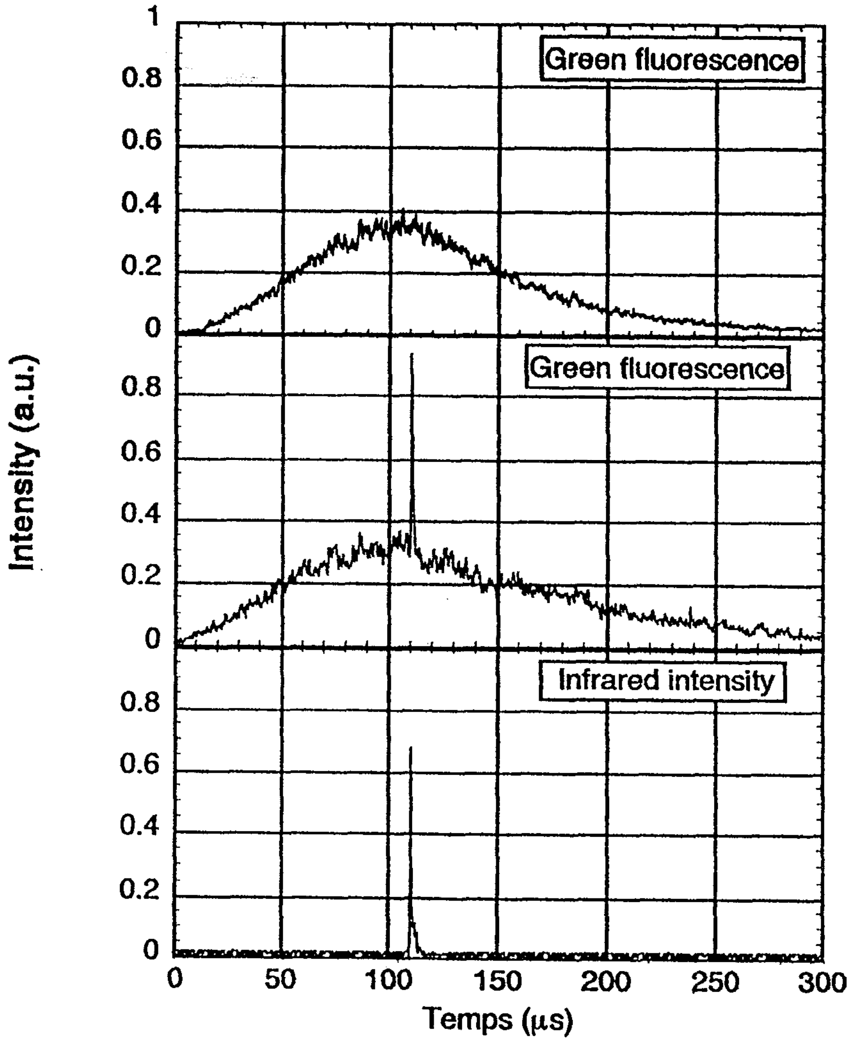


Fig. 1.a

Fig. 1.b

Fig. 1.c

Figure 2

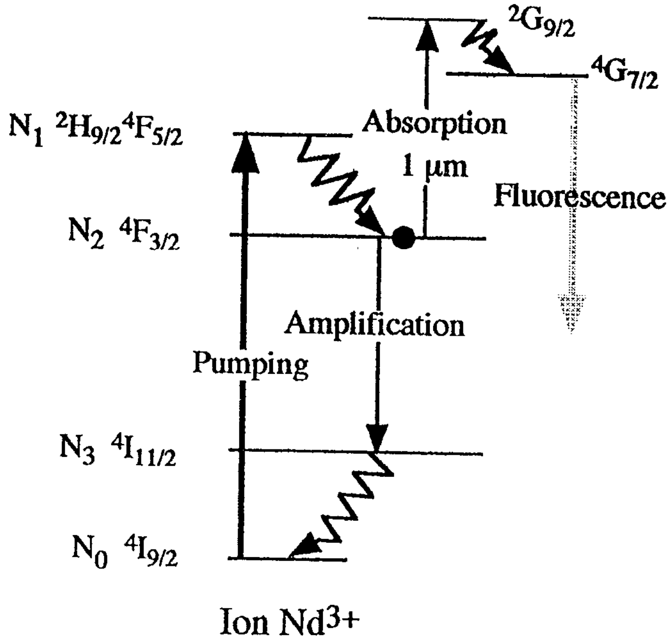


Figure 3

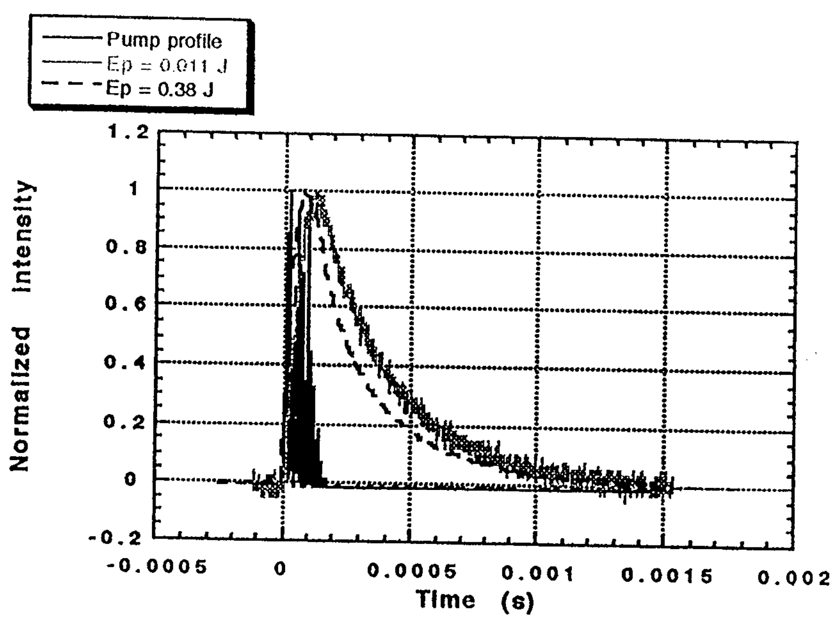


Figure 4

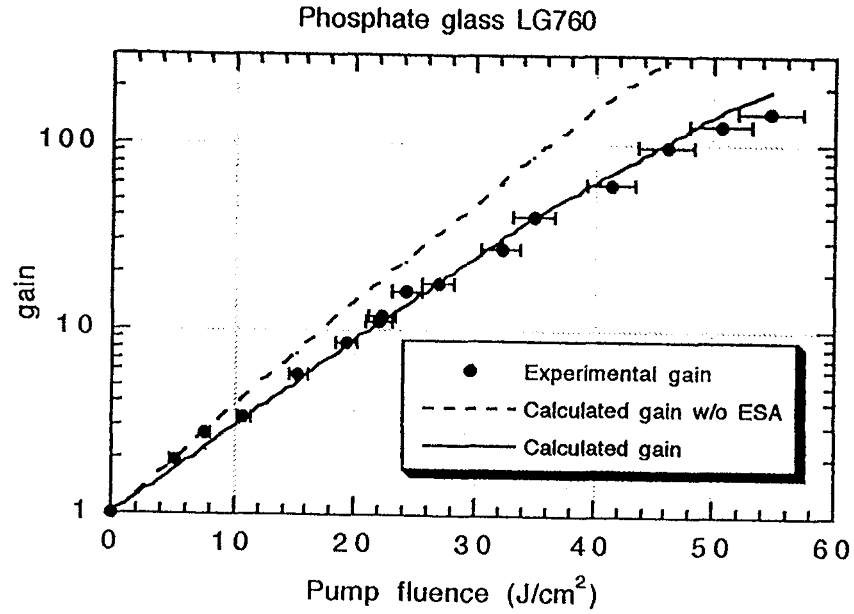
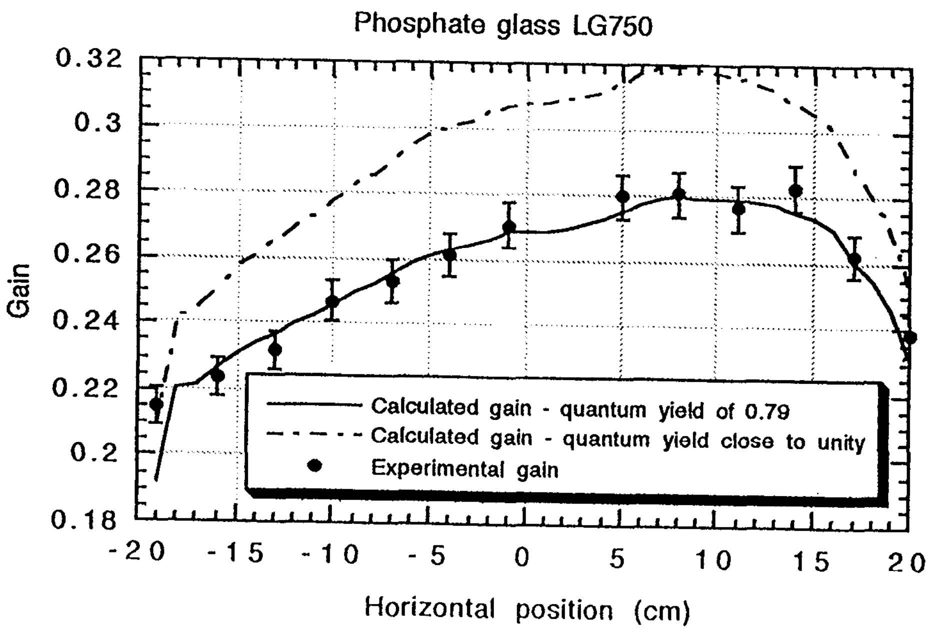


Figure 5



Thin film contamination effects on laser-induced damage of fused silica surfaces at 355 nm *

F. Y. Génin, A. Burnham, M. D. Feit,
A. M. Rubenchick, J. Yoshiyama,
University of California, Lawrence Livermore National Laboratory,
Livermore, California 94550, U.S.A.

A. Fornier, C. Cordillot, and D. Schirman,
CEA-Centre d'Etudes de Limeil-Valenton
94195 Villeneuve-Saint-Georges - Cédex, France.

To simulate target chamber contamination of debris shields, fused silica windows were artificially contaminated. Several forms of contamination were studied: particulates and very thin films. The contaminants were prepared by sputtering various materials (Au, Al, Cu, and B_4C) onto the surface to produce a uniform thin film (1 to 5 nm thick) or by depositing thicker layers (1 µm) through a mask to generate thick particles (10 to 250 µm in diameter). The samples were then tested at 355 nm in air and vacuum with a 3-ns Nd:YAG laser. The laser-induced damage threshold (LIDT) was measured as a function of film thickness and film composition and the damage morphologies were characterized by Nomarski optical microscopy and SEM.

The results showed that thin film contamination leads to a drop in LIDT which is independent of the quality of the surface finish. The LIDT was very uniform over the sample (e.g. 6 J/cm^2 for 5 nm of Cu). The damage morphology characterization showed that while metals led to the disappearance of pit formation, B_4C led to a higher density of such pits. The tests also showed a difference in damage behavior between air and vacuum. These results will be discussed using a simple light absorption model to explain the LIDT dependence on film composition and thickness.

*Work performed under the auspices of the U. S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-ENG-48, by the Mégajoule Project (CSL-CEA, Department Limeil-Valenton), and the French Ministry of Defence.

Statistical evaluation of damage risks in NIF and LMJ optics at 355 nm *

F. Y. Génin, A. Rubenchick, M. D. Feit, L. Sheehan, M. R. Kozlowski
University of California, Lawrence Livermore National Laboratory,
Livermore, California 94550, U.S.A.

J. Dijon , and P. Garrec,
LETI - CEA - DOPT - Couches Minces pour l'Optique (CMO), CENG,
17, avenue des Martyrs, 38054 Grenoble, Cedex 09, France.

A statistical study of laser damage in fused silica was performed at 355 nm to evaluate and predict the potential for failure of NIF and LMJ optics during high fluence operation. In particular, the study attempted to identify the influence of various defects in polished synthetic fused silica on damage and rank the importance of parameters that can determine their resistance to damage. The defects include mechanical imperfections (scratches, sub-surface modifications) and chemical imperfections (bubbles, inclusions, surface contamination). The parameters that were varied include the type of fused silica, the polishing process, the cleaning method, the sample thickness and the sample diameter.

All samples were irradiated at 20° incidence angle with a 6.5-ns and 8-ns-pulse at 355 nm on automated damage testing systems at CMO and LLNL. The laser-induced damage threshold (LIDT) was measured on a minimum of 100 sites for each sample to gather sufficiant statistical information. The damage morphology was characterized to investigate the origin of damage initiation.

The statistical damage curves were very reproducible. The LIDT and the density of damage precursors were most influenced by the polishing process. The fused silica type, the cleaning method, and the sample diameter had secondary effects on the LIDT. A thickness effect and bulk damage was noticed for areas with very high LIDT. Sample cleaning was found to play a role in reducing the number of low LIDT sites, thereby affecting the statistical behavior of the lower part of the statistical distribution. Finally, the statistical damage curves allowed preliminary predictions of the risk for damage intiation in the population meter-size optics that will be used in NIF and LMJ.

*Work performed under the auspices of the U. S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-ENG-48, by the Mégajoule Project (CSL-CEA, Department Limeil-Valenton), and the French Ministry of Defence.

Abstract for the 1998 SSLA-ICF Third Annual Conference

Diffraction modeling of the National Ignition Facility (NIF) Optical Pulse Generation (OPG) system and integration into the end-to-end system model

Mark Henesian, John K. Crane, Brent Dane, Jim Davin, Lynn Kott, Curt Laumann, Janice Lawson, Mikael Martinez, Bryan Moran, John Miller, Rick Sacks, Ken Skulina, and Wade Williams

Lawrence Livermore National Laboratory

P. O. Box 808, Livermore, CA 94550

Phone: (510) 423-1504; FAX: (510) 422-7748

email: henesian1@llnl.gov

Abstract

A detailed beam propagation/ energy extraction model for the National Ignition Facility (NIF) Optical Pulse Generation (OPG) system has been integrated into a significantly upgraded model of the main NIF laser chain - including the Pre-Amplifier Module (PAM), the Input Sensor Transport Leg (ISP), the Pre-Amplifier Transport Leg (PABTS), and Injection Telescope system. The PROP92 code is used for these end-to-end system simulations. We discuss the inclusion of optical component wavefront measurements into the model, and compare with recent performance results in the PAM prototype laboratory. The impact of OPG spatial beam profile shaping, beam modulation and contrast, and wavefront aberrations on integrated NIF system performance will be discussed. We also discuss beam edge-shaping techniques and requirements, and the impact on whole-beam self-focussing, optical damage, and intensity modulation in the PAM and main NIF laser chain. Wavefront and fluence contrast measurements from the prototype PAM will be compared with simulations.

Work performed under the auspices of the U. S. Department of Energy by Lawrence Livermore National Laboratory under contract W-7405-Eng-48.

Design Optimization for Main Amplifier Stage of Technical Integration.Line(TIL)

F. Jing , X. Zhang , Q. Zhu, Y. Man and H. Peng

Laboratory for Laser Fusion
Southwest Institute of Nuclear Physics and Chemistry
P.O.Box 525-80, Chengdu 610003, P. R. China,
Fax: 86-(816)-2271598

A four pass amplifier system with small aperture beam reverser was optimized as the main amplifier stage of Technical Integration Line(TIL) of Shengguang-III Laser Facility by using a 2-D beam propagation code to reach the goal of 1.5kJ and 1.5TW from one beam in the third homarnic generation. Two schemes were considered in the optimization, one of them employed only small aperture Pockels cell in the reverser, and the other used both the smaller one and a larger one in the main beam line. Amplifier parameters and frequency converter were not included in this optimizing proccess, they would be discussed in other cases. Some parameters of system were fixed, such as the output beam aperture(25cm) and disk thickness(4cm). Tens of varibles(disk counts and configurations, temporal and spatial shape of input pulse, etc.) were optimized under the conatraints of amplifier gain, fluency damage/filamentation and so on. As a result, 14 disks will meet the need of TIL, and the basic requirements for the optical components have been thoroughly analyzed.

CEA, Centre d'études du CESTA, Département des Lasers de Puissance / Service Conception des Systèmes Lasers

A. Jolly, M. Urbanik, Ph. Estraillier

Programmable generation of high voltage pulses for Pockels cell modulators.

Abstract

An original design for electro-optical pulse shaping is presented, which provides high voltage - fast programmable waveforms to be operated with 4 to 20 mm² useful area Pockels cell amplitude modulators. The challenge consists of building electronically controlled voltage pulses together with a very high temporal resolution. The whole assembly consists of three subsystems, namely the high voltage - short pulse generator, the shaper, and the modulator. In the present paper, we only report the performances of the shaper.

The concept makes use of diode lasers together with photoconductors, which are operated as quasi static variable resistances and allow distributed coupling between two microstrip lines. When triggered with a short pulse, the latter arrangement forms an arbitrary waveform in the following way : 10 to 30 voltage steps (or more if required), whose heights are related to the current flowing through the corresponding set of photoresistances, add together at different time steps to build the suitable waveform. The time steps come from the propagation delay along a piece of transmission line, between the photoresistances.

Photoresistances are made of planar, low dark conductivity, thin intrinsic Silicium bars. A high power 980 nm laser diode bar is closely coupled onto the upper side, which provides electronic control of the current step inside Silicium by varying the current in the diode laser.

Two prototypes of the shaper were built, using microstrip lines whose lengths are 1.20 and 2.40 m, onto large dielectric sheets with ε_r = 2.5 and 10 from 0 to 10 GHz. When triggered with a Kentech pulser, at 100 ps transition time from 0 to + 4 kilovolts, the shapers lead to the following results:

peak output voltage (KV / 50 Ω)	time resolution / shaper alone (ps)	time resolution / overall system (ps)	pulse width (ns)	ε_r dielectric sheet
2	180	210	3.5	2.5
2	230	270	3.5	10
2	330	360	7	10

The high voltage effective limit in the operation of our prototype is shown to be higher than that indicated in the above table, because the maximum 2 kilovolts directly come from the available amplitude from the pulser (4 kV max.). Other measurements with 20 ns wide pulses indicate that our prototypes can be operated at up to 5 kilovolts peak output voltage. We also make evidence of an effective amplitude dynamics exceeding 50 dB, in the definition of one voltage sample.

As a conclusion, this waveform shaping technology should be useful for fiber smoothing in the Laser Méga Joule program (also see Phebus facility) and, if the needs appear, open the route for designing a completely multimode front end system. A number of other applications could also be founded for pulse shaping in the field of high energy sources.

The HF Beam Wiggler Test in the Single Pulse Operation Mode

A. N. Kolomiysky, N. G .Kovalsky, V. V. Kryzhko, K. R. Manes(*), M. I. Pergament

Troitsk Institute for Innovation & Fusion Researches, Troitsk, Moscow Reg. 142092
Russia, Phone 7-095-334-0686, Fax 7-095-334-5776, E-mail: pergam@fly.triniti.troitsk.ru

(*) Lawrence Livermore National Laboratory, Livermore, CA 94550 USA,
Phone 1-510-422-6228, Fax 1-510-423-6506, E-mail: manes1@popsiele llnl.gov

It is known that to avoid the filamentation of laser beam in laser produced plasma and to control the spatial distribution of X-ray sources at hohlraum walls, the rapid motion of the laser beam focal spot can be used. For this purpose the 1-cm clear aperture Quadruple Electrooptic Beam Wiggler with operation frequency of 6.5 GHz and angular deflection of ±4 dif. limits has been developed, constructed and successfully tested [1].

The other way of "smoothing" of the laser beam far field intensity distribution is using the Beam Wiggler to provide fast (0.5-1 ns) transverse jumps of the focused laser beam over the target surface up to values corresponding to several spot diameters. This way of the focal spot intensity distribution control is expected will be particularly effective for X-ray sources distribution "smoothing" at the inner walls of the hohlraum for the indirect – drive ICF approach. Therefore the Beam Wiggler for operation in the single pulse mode to provide fast nanosecond transverse jumps of the laser beam was redesigned and tested. To provide nanosecond transverse jumps of the focused laser beam the high voltage pulsed nanosecond generator for the Beam Wiggler control was designed and tested. The Beam Wiggler operation in the single pulse mode was accomplished, laser beam focal spot deflection of about ±6 dif. limits was measured. Both static and dynamic testing experiments allow us to conclude that the developed electrooptic deflector makes it possible to control the direction of a laser beam with up to 1 cm clear aperture without noticeable distortions of the wave front quality.

Experimental trials of the developed Beam Wiggler both in high frequency and single pulse operation modes showed that using of this device can be proposed as an efficient method for the smoothing of laser beam intensity distribution at the surface of ICF targets.

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Using a Design of Experiment method to improve KDP crystals machining process.

Philippe LAHAYE, Christian CHOMONT, Pierre DUMONT

SAGEM SA
BP 20 86280 S^t BENOIT FRANCE
Tel : 33 5 49 37 43 45 Fax : 33 5 49 37 43 03
Email : Philippe.lahaye@sagem.fr

Jacky DUCHESNE, Geneviève CHABASSIER

CEA-LV
94195 Villeneuve S^t Georges cedex

Surface quality is an important issue for KDP crystals implemented in high power lasers. Single Point Diamond Turning is the only way to get the required transmitted wavefront and damage threshold, specially in the UV band of the laser Mégajoule.

The aim of the process development was to reach an rms roughness lower than 3 nm using a vertical fly-cutter, an appropriate cleaning equipment and an interferometric microscope for measurements.

A Taguchi Design of Experiment method has been used to optimize the fly-cutting process parameters on 100x100 mm^2 KDP crystals.

Based on SAGEM's extensive experience, the first step was to find the various parameters which have a direct influence on surface quality using a brain storming method (22 parameters were listed).

Secondly, we reduced this number by setting values or rejecting factors from previous works on that subject or similar ones.

Thirdly, after selecting less than 10 parameters, we determined 2 levels for each of them. The pertinence of the results strongly depends on adequately choosing these 2 levels.
We paid a lot of attention to this step because we were convinced that the starting roughness level should be less than 10 nm.

Fourthly, we started the Design of Experiment itself using a L 16 Taguchi chart which corresponds to 16 experiments in order to define the best combination, then we performed the same test 6 times to estimate the residual variance. It was of great importance to carry out these 22 experiments with particular care. We have duplicated those which seemed suspicious to us.

In conclusion the result of the Design of Experiment gave us the best level for each parameter. It also determined 4 main-effect parameters.

Repetitive cuttings with the best combination above mentioned led to an average 1.1 nm rms roughness with a standard deviation of 0.32 nm (at 0.125 mm cut-off length).

This work was supported by CEA-LV, as part of the Laser Mégajoule Program.

NIF Optical Specifications -
The Importance of the RMS Gradient Specification

J. K. Lawson, J. M. Auerbach, M. A. Henesian, R. A. Sacks, R. E. English, Jr., J. B. Trenholme, W. H. Williams
Lawrence Livermore National Laboratory
Livermore, CA 94551

ABSTRACT

The performance of the National Ignition Facility (NIF) (especially in terms of laser focusability) will be determined by several key factors. One of these key factors is the optical specifications of the thousands of large aperture optics that will comprise the 192 beamlines. We have previously reported on the importance of the specification of the power spectral density (PSD) on NIF performance. Recently, we have been studying the importance of long spatial wavelength (> 33 mm) phase errors on focusability. We have determined the preferred metric for determining the impact of these long spatial wavelength phase errors is the rms phase gradient. In this paper, we , outline the overall approach to NIF optical specifications, detail the impact of the rms phase gradient on NIF focusability, discuss its trade-off with the PSD in determining spot size and review measurements of optics similar to those to be manufactured for NIF.

*Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

3D Gain Modeling of the LMJ and NIF Amplifiers

G. Le Touzé, O. Cabourdin, J.-F. Mengué,
M. Guénet, E. Grebot and S. Seznec

CEA Limeil-Valenton, DRIF/DLP,
94195 Villeneuve St-Georges, France

K. S. Jancaitis, C. D. Marshall, L. Zapata and A. E. Erlandson

Lawrence Livermore National Laboratory
P.O. Box 808, L-441
Livermore, Ca 94550

Abstract

A 3D ray-trace model has been developed to predict the performance of flashlamp-pumped laser amplifiers. The computer program, written in C++, includes a graphical display option using the Open Inventor library, as well as a parser and a loader allowing the user to easily model complex multi-segment amplifier systems. It runs both on a workstation cluster at LLNL (using PVM), and on the T3E Cray at CEA. We will discuss how we have reduced the required computation time without changing precision by the optimizing the parameters which set the discretization level of the calculation. As an example, the sampling of calculation points is chosen to match the pumping profile through the thickness of amplifier slabs. We will show the difference in pump rates calculated with our latest model as opposed to those predicted by our earlier 2.5D code, AmpModel.[1] We will also present the results of calculations which model surfaces (e.g. AR coatings on blastshields) and other 3D effects such as top and bottom reflector positions and reflectivity which could not be included in the 2.5D model.

This new computer model also includes a full 3D calculation of the amplified spontaneous emission rate in the laser slab, as opposed to the 2.5D model which tracked only the variation in the gain across the transverse dimensions of the slab. We will present the impact of this evolution of the model on the predicted stimulated decay rate and the resulting gain distribution.

Comparison with most recent AmpLab experimental results will be presented, in the different typical NIF and LMJ configurations ("Diamond", "X", and "Inner").

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Thermal recovery of LMJ and NIF amplifiers

G. Le Touzé, Ph. Arnoux*, J.P. Caltagirone**,
B. Bicrel, E. Grebot, S. Seznec

CEA Limeil-Valenton, DRIF/DLP,
94195 Villeneuve St-Georges, France

*CEA CESTA, DEV/SDET, 33 Le Barp, France

**Laboratoire MASTER, ENSPCB, 33 Pessac, France

S. B. Sutton, C. D. Marshall, A. E. Erlandson

Lawrence Livermore National Laboratory
P.O. Box 808, L-441
Livermore, Ca 94550

Abstract

LMJ/NIF shot rate is limited by thermal recovery of laser slabs and beamtubes. Most of the electrical energy input is dissipated thermally in the amplifiers. Wall-plug efficiency is around 1% (400 MJ per shot vs 4 MJ @ 1ω). Wavefront distortion due to non uniform heat deposition or thermal gradient in gases can only be corrected in the limits of the adaptative optics. Laser focusing requirements thus dictate a maximum chain aberration which can be expressed in wavefront distortion per slab per pass and lead to thermal recovery requirements. Aberrations can be analyzed in terms of residual temperature differences in slabs and gas columns of amplifier cavities and beamtubes, but it will be shown that more precise requirements have to be established, accounting for the geometry of temperature and displacement maps.

In order to keep all low frequency optical aberrations on the beam path within reach of the adaptative optics, heat has to be extracted before the next laser pulse is shot. Because of low conductivity of glass and poor thermal coupling between slabs and blastshields, no cooling would result in more than 12 hours before reaching thermal requirement. The expected shot rate can only be achieved with an active cooling of flashlamps. A complete modeling of thermal effects in amplifiers and beamtubes has been performed to dimension the cooling system. This thermal modeling includes : 1.

balance of energy deposition in the amplifiers, 2. 3D modeling of laser slabs thermal recovery, 3. thermo-optical modeling of stationary wave-front distortion in slabs, 4. 2D and 3D modeling of natural convection in amplifier cavities and tubes. Optical distortions in slabs and gas columns result from the combination of initial energy distribution in the amplifier and thermal equilibrium between the different amplifier parts. The heat deposition leads to a prompt temperature elevation of all elements of the amplifier : lamp envelopes, blastshields, slabs, claddings, etc. AmpLab thermal data has provided new thermal inputs for starting conditions to base the models on. The better understanding of amplifier thermal behavior, reached through this modeling effort, enables us to propose improvements to amplifiers and beamtubes, such as slab mask convective cooling, beamtube radiative cooling, boundary layer capture, in order to bring down initial recovery time and reach higher shot rates.

Temporal response diagnostic for the *Laser MégaJoule*

P.LECLERC, V.ALLOUCHE
Commissariat à l'Energie Atomique (CEA)
CEA-DAM
DCRE/SEIM/L2E
BP 12
91680 BRUYERES LE CHATEL
FRANCE
Tel. : +33.1.69.26.47.71 - Fax. : +33.1.69.26.70.43
e-mail : leclerc@bruyeres.cea.fr
Presentation : poster

Abstract :

The *Laser MégaJoule* requires very precise beam-to-beam power balance. Moreover, each laser pulse will have a particular temporal response to generate specific effects such as mechanical compression, plasma heating, and ignition. To control the proper operation of the facility, several kinds of measurement systems have to be developed for beam diagnostics. The temporal shape diagnostic is a critical one.

The LMJ will generate 20 ns wide pulses with a peak-to-foot contrast ratio of up to 300 :1, with a rise time as short as 100 ps. The pulse shape must be known with a 2% accuracy (rms error on a 2 ns sliding window), and the diagnostic system must check that the extinction ratio is above 10^5 before the foot of the signal.
To achieve such performances, the temporal shape diagnostic must have a dynamic range of 7500, and a bandwidth near 10 GHz. It must also be the least expensive as possible to be implemented in 3 locations per beam (meaning a need for 720 diagnostic systems).

An original design had to be found to face that specific need that exceeds the capabilities of standard instrumentation. We propose a diagnostic system built around a commercial real time digitizer and two optical receivers. The use of optical fibers allows vertical multiplexing of several signals to increase the measurement dynamic while temporal multiplexing reduces prices. Operating receivers and digitizers above their maximum ratings was carefuly studied, with special concern for linearity, and recovery time after saturation. The study of the optical injection system was also a critical point.

Modeling and characterizations have been performed on the different sub-parts to validate our measurement system. Then a global validation campaign was conducted on the *Phebus* laser facility. It showed that our diagnostic reaches the needed dynamic range at an acceptable price. But its bandwidth is limited at 1 GHz, thus restricting temporal response diagnostic to 1 ns rise-time pulses (or 500 ps with some restrictions).

Temporal response diagnostic for the LMJ using a commercial digitizer appears to be a valid concept, but some enhancements are still needed. We will keep working on that system to adapt it to 3ω wavelength, to automate the optical injection system and to enhance its bandwidth by using new types of real time digitizers.

Suppression of the small-scale intensity non-uniformity introduced by array focus systems

Baida Lü, Bin Zhang, Bangwei Cai

Institute of Laser Physics & Chemistry
Sichuan University, Chengdu 610064, China
Tel: 0086-28-5223875-62819
Fax: 0086-28-5222844, 5222187
E-mail: badalu@pridns.scuu.edu.cn

Abstract

In this paper, a crossed segmented wedge array focus system has been described, which is capable of achieving two-dimensional uniform irradiation on the target with a controllable width from several hundred microns to millimeters. Then, the speckles introduced by multiple interference of optical arrays, which can result in small-scale intensity non-uniformity, have been studied in detail. The projection detecting technique has been used to measure interference speckles and fringe separations .The experiments have been compared with the numerical results, showing a good consistency. Finally, several methods for the suppression of small-scale intensity non-uniformity have been analyzed based on the diffraction integral calculations. The results obtained would be useful for improving irradiation uniformity on the target.

Effects of KDP crystals gravity sag on third harmonic generation

Olivier LUBIN[1], Claude GOUÉDARD
Commissariat à l'Énergie Atomique - France

Abstract.

The crystal deformation due to the gravitational sag can affect the frequency conversion in two ways. Firstly, the stresses generate spatial variations in the refractive index tensor through the stress-optic effect, which makes it impossible to meet the condition for phase matching at all positions in the crystal. Secondly, the faces deflection results in phase matching detuning by a change in the refraction angle.

In order to predict these effects, the sag analysis is performed using a structural code (FEM), which takes into account the anisotropic mechanical properties of KDP plates. Then, the changes in the refractive indices are calculated from the stresses map, and the deflection values of the input face of the crystal are calculated at each point of a 50×50 grid. The effect of KDP sag on frequency conversion is computed using the Miró propagation code. To simulate the deformation of the crystallographic axes, the deflection values are converted into a phase mask which is applied on the incident beam.

In the context of mounts design, several configurations of support have been modelled. Considering a type I - type II scheme and the worst inclination of KDP plates from vertical position in the LMJ design (62°), the results of the calculations show that the changes in the refractive indices are negligible in all cases (less than 10^{-5}). On the other hand, the crystals sag may reduce the conversion efficiency of several per cent. For the system of support envisaged at the present time, a reduction of 3% is expected in the third harmonic conversion efficiency.

ENERGY BANK OF « LASER MEGAJOULE » AT C.E.A.

J.-P. Marret, D. Rubin de Cervens, P. Père, P. Patelli, J.-C.Naud, D. Esteban
C.E.A. Limeil Valenton - 94195 VILLENEUVE St GEORGES CEDEX - FRANCE

450MJ will be stored in the capacitor bank charged under 24kV, but a smaller facility of 20MJ - 26kV, called « Ligne Intégration Laser », must previously be built to test the components and validate the conceptual design which is proposed. A lot of progress has already been made in the efficiency, reliability, durability, safety and cost of capacitors from Burgondy. On the contrary, no choice has been made about the main energy switches ; that is why vacuum or pressurised gas sparkgaps and semiconductor devices should be studied in the range of 125 - 250kA.

Broad-spectrum pulse calculations using the *Miró* software

O. Morice*and V. Rivoire†
Centre d'études de Limeil-Valenton
94195 Villeneuve Saint Georges Cedex – France
Tél : 01 45 95 68 20
Fax : 01 43 86 74 07
Email : morice@limeil.cea.fr

Poster preferred

The *Miró* software has been developped for a few years in CEA/LV to simulate the propagation and the amplification of laser beams in laser devices such as Mégajoules or NIF. It simulates the propagation of light doing the paraxial approximation. Then the equation of propagation, involving Kerr effect and diffraction, is a nonlinear Schrödinger equation, which is solved by an usual Fourier-transform algorithm. *Miró* has been developped using the C++ language, and a user-friendly interface has been inplemented, allowing a beginner to use *Miró* without a long initiation.

In previous versions of *Miró* the assumption of monochromatic beams was done. Particularly, the laser amplification (in Nd slab amplifiers) was solved using the well-known Frantz & Nodvik analytical formula. However, thermonuclear fusion experiments in high-power laser require an as uniform as possible irradiation of the target. A good way to obtain such a result consists in breaking the coherence of the laser, *i.e.* use partially coherent pulses: we talk of ***smoothed pulses.*** Smoothed pulses can be obtained by several methods — smoothing by spectral dispersion (SSD) and smoothing by optical fibers (SOF) are the most common of them. Both of these methods involve a broadening of the laser spectrum.

The way for simulating broadband pulses consists in taking a lot of time steps to sample the temporal fluctuations of the electric field envelop. The advantage of such a method is that it suits for all kind of non-monochromatic beams. In that way, performance comparaison of the different smoothing methods can be done. The code can also been used for simulating chirped pulse propagation, as used in the Petawatt experiments. However,

*CEA/DRIF/DLP
†CISI

the drawback of this code is the need of memory which can be consequent for broad-spectrum and long-duration pulses. This problem can be solved by using a parallel machine with a large amount of memory. Another way is to simplify the conditions of the simulation, for example by keeping only a temporal part of the pulse, or by less sampling the spatial dependance of the field to save memory.

The "broadband spectrum" mode of *Miró* takes into account the same physical effects as the monochromatic modes, that is diffraction, Kerr effect, birefringence, aberrations, saturated amplification, and frequency conversion with walk-off. In addition, specific spectrum-related effets are treated. First of them is the group velocity dispersion in material. This effect is solved by making a Fourier transform of the field with respect to the time variable. Combinating this with the Kerr effect (*i.e.* the phase automodulation) require a sampling of the z propagation in order to treat alternatively the Kerr and the dispersion effects. Additionaly, in frequency converters, the group velocity difference between harmonics is taken into account and spectraly solved. This effect is responsible of a loss of conversion efficiency for some kinds of non-monochromatic beams.

The case of amplification is more complicated, because the finite Nd linewidth has to be taken into account. However, the evolution of the gain due to saturation disallows a direct spectral resolution. This two time-scales problem is solved numericaly by a peculiar method: the pulse is first splited in several temporal "slices". Those "slices" are thin enough so that saturation during the corresponding duration can be neglected, and still thicker than the inverse of the Nd linewidth. In that condition, we can solve the broadband amplification spectrally by restricting the problem to a slice. The evolution of gain by saturation is calculated afterwards and a correcting term is applied to the field in order to take the saturation into account. Note that such a resolution is valid for sufficiently long pulse, and this condition generally holds for high power laser setups.

The diffraction of beams by grating will also be treated soon. This is a linear problem which allows an all spectral treatment. We can note however that the wave diffracted by a grating is an inhomogeneous one. A peculiar treatment of such waves, involving a $t \rightarrow t - \xi x$ variable change, will permit simulations without needing a precise spatial sampling. With this change the dispersion by grating will be treated analogous to the group velocity dispersion by material.

Finaly the *Miró* "broadband spectrum" mode allows simulation of all type of non-monochromatic beams generally used on high-power laser setups. The conference presentation will include a detailled description of the physical models taken into account and of the numerical resolution, and some examples related to the Mégajoules smoothing simulation.

Spatial Filter Issues

J.E. Murray, D. Milam, K.G. Estabrook, C.D. Boley

University of California
Lawrence Livermore National Laboratory
Livermore, CA 94550 USA
E-mail: murray4@llnl.gov
Phone: (510) 422-5481; Fax: (510) 423-5517

ABSTRACT

We used Beamlet measurements to investigate three spatial filter issues for NIF: the maximum permissible spatial filter pressure, the smallest pinhole that will remain open for a full-energy ignition pulse, and back reflections from pinholes.

Beamlet measurements determined the threshold pressure, p(th), for the cavity (CSF) and transport spatial filters (TSF) on NIF. We defined p(th) as that pressure which results in the first visible distortion on the near field of the transmitted pulse. We were able to measure p(th) for the NIF CSF directly at the highest output power anticipated for NIF, 5.5 TW, because the F-numbers of the NIF CSF and the Beamlet spatial filters are reasonably close, 32 and 26, respectively. However, the F-number of the NIF TSF is 80, more than 3x that of the Beamlet spatial filters, and off-line measurements[1] showed a strong p(th) dependence on F-number. Since we could not measure p(th) for the NIF TSF at the appropriate power and F# simultaneously, we reduced the size of the Beamlet aperture by 3x to give an F/78 beam and measured p(th) using the highest power possible with the 9x reduced beam area. We then extrapolated to NIF powers using the p(th) dependence on power obtained at F/26. These measurements gave a p(th) value of .006 Torr for the NIF CSF and extrapolated to .002 Torr for the NIF TSF. Although we found that beam modulation increases only slowly with pressure above p(th), we did observe a significant back reflection at ~2.5xp(th), so we recommend that NIF run its spatial filters at ~p(th)/10 to provide an adequate operational safety margin.

Regarding pinhole closure, simple scaling arguments indicate that the pass-4 pinhole in the NIF CSF will be the hardest pinhole to keep open. At that location, the required 1ω pulse shape to deliver a 1.8 MJ 3ω ignition pulse to the target has a contrast of 21:1, with 22% of its energy in the 20-ns square "foot" of the pulse. We used this pulse shape to test three pinhole types[1]: washer, azimuthally-segmented, and cone pinholes.

* This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory, under contract number W-7405-ENG-48.

We found that the cone pinhole is the best of the three with regard to both closure and back reflections. A ± 150 μrad stainless-steel cone pinhole remained open for a 12.9 kJ ignition pulse, shaped as required for the pass-4 pinhole of the NIF CSF. This 12.9 kJ is 87% of the energy needed to deliver 1.8 MJ of 3ω to the target on NIF. We stopped the tests at 12.9 kJ because of a damage threat to the Beamlet cavity polarizer.

We also observed back scatter from pinholes, which originates from the edges of the pinhole. Cone pinholes back scattered less than washer-type or azimuthally-segmented pinholes, and the back scatter from the cone pinhole remained linear with power into the spatial filter and remained small enough in magnitude to be inconsequential. In contrast back scatter from the other two pinhole types increases nonlinearly with power to the point that injection mirrors were damaged.

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Plasma Electrode Pockels Cell for the National Ignition Facility *

Mark A. Rhodes, Scott Fochs, Peter Biltoft, Terry Alger, Bill Funkhouser, Charles D. Boley

P.O. Box 808, L-490
Lawrence Livermore National Laboratory
(510) 422-9114, Fax (510) 422-7748, email: rhodes4@llnl.gov

The National Ignition Facility (NIF), now under construction at Lawrence Livermore National Laboratory, will be the largest laser fusion facility ever built. The NIF laser architecture is based on a multi-pass power amplifier to reduce cost and maximize performance. A key component in this laser design is an optical switch that closes to trap the optical pulse in the cavity for four gain passes and then opens to divert the optical pulse out of the amplifier cavity. The switch is comprised of a Pockels cell and a polarizer and is unique because it handles a beam that is 40 cm × 40 cm square and allows close horizontal and vertical beam. Conventional Pockels cells do not scale to such large apertures or the square shape required for close packing. Our switch is based on a Plasma-Electrode Pockels Cell (PEPC).

In a PEPC, low-pressure helium discharges (1-2 kA) are formed on both sides of a thin slab of electro-optic material (typically KDP). These discharges form highly conductive, transparent sheets which allow uniform application of a high-voltage pulse (17 kV) across the crystal. A 37 cm × 37 cm PEPC has been in routine operation for two years on the 6 kJ Beamlet laser at LLNL. For the NIF, a module four apertures high by one wide (4×1) is required. However, this 4×1 mechanical module will be comprised electrically of a pair of 2×1 sub-modules.

Recently, we demonstrated full operation of a prototype 2×1 PEPC. In this PEPC, the plasma spans two KDP crystals. A major advance in the 2×1 PEPC over the Beamlet PEPC is the use of anodized aluminum construction which provides sufficient insulation to allow formation of the planar plasmas.

Now we are operating a full 4×1 prototype. In this paper, we will discuss the design and test results of the device.

*This work was performed under the auspices of the US Department of Energy by Lawrence Livermore National Laboratory under the contract number W-7405-Eng-48.

Polarization Smoothing for NIF

Joshua E. Rothenberg

Lawrence Livermore National Laboratory, L-439,P. O. Box 808, Livermore, CA 94551
Telephone: (510) 423-8613 , FAX: (510) 422-5537 , Email: JR1 @ LLNL.GOV

ABSTRACT:

Recent simulations[1] have shown that filamentation in a NIF-like hohlraum plasma is dramatically suppressed by polarization smoothing (PS),[2] which is the superposition on target of two orthogonally polarized and distinct speckle patterns. As a result, a significant improvement in laser performance and focal spot size may result from the use of PS, which might eliminate or reduce the need for SSD and its associated divergence. The essential requirements for an implementation of PS to be optimally effective are that the beam power be split equally between the polarizations and that the orthogonally polarized speckle patterns be completely uncorrelated. PS is being tested in FY98 on Nova using slightly wedged KDP crystals which split the 3w beam into orthogonally polarized beams with a small angular deviation. The prospects of this scheme for NIF, which requires the addition of a KDP crystal in each of 192 UV beams, would appear to be hampered owing to the cost of implementation and increased damage threat and B - integral.

It is suggested here that the preferred scheme for PS on NIF is to impose stress birefringence on an existing fused silica optic in either 96 or 192 of the UV beam paths. This approach adds no B - integral and requires little additional border around the optic. In the preferred scheme, a wave plate is created by stress birefringence which is nearly uniform over an entire Beamlet aperture. Perhaps the most straightforward scheme to achieve a 50/50 polarization mix is to rotate the polarization on two out of four Beamlets in a quad with a half-wave plate. Alternatively, one could use four quarter-wave plates to put two Beamlets into right circular polarization and two into left. For quarter-wave retardance, the shear stress required is ~ 180 PSI, and at twice this stress level a half-wave plate can be generated, and this stress level is still well within practical limits. For optimal PS these approaches require ~10% accuracy in the amount of stress imposed to achieve the necessary retardance. In a second scheme one imposes a highly nonuniform stress pattern in an optic in every beam line. Generally, much larger stress levels are required in this approach, but precision is not required. These schemes of PS are analyzed, both in terms of the ease of implementation, and the smoothing behavior on target. A comparison of the smoothing as a function of spatial frequency on target is presented, both for schemes involving stress birefringence and the more conventional scheme which uses wedged KDP.[2]

This work was performed under the auspices of the U. S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

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The issue of FM to AM conversion on NIF

Joshua E. Rothenberg

Lawrence Livermore National Laboratory, L-439,P. O. Box 808, Livermore, CA 94551
Telephone: (510) 423-8613 , FAX: (510) 422-5537 , Email: JR1 @ LLNL.GOV

ORAL PRESENTATION PREFERRED

ABSTRACT:

The National Ignition Facility (NIF) baseline requires phase modulation for two purposes. First, ~ 1Å of frequency modulation (FM) bandwidth at low modulation frequency is required to suppress buildup of stimulated Brioullin scattering in the large aperture laser optics. Also ~ 3 Å or more bandwidth at high modulation frequency is required for smoothing of speckle structure illuminating the target by the smoothing by spectral dispersion method (SSD). Ideally, imposition of bandwidth by pure phase modulation does not affect the beam intensity. However, as a result of a large number of effects, the FM converts to amplitude modulation (AM) which, in general, adversely affects the laser performance (e.g. by reducing the margin against damage to the optics). The conversion of FM to AM is always a result of nonuniform spectral transmission (either in amplitude or phase) of the FM bandwidth. The effects which cause FM to AM include group velocity dispersion (nonuniform phase), variation of gain over the bandwidth, clipping of pinholes (SSD disperses the bandwidth in the far field), etalon effects, spectral dependence of coatings, propagation away from SSD grating and its image planes, beam motion on optics owing to SSD, and polarization dispersion effects.

Interference of light which has propagated in both polarization modes of a "polarization maintaining" (birefringent) fiber generates an etalon-like effect, and imposes very stringent requirements on the components in the all-fiber NIF oscillator and distribution sub-systems. This effect originates from the relative delay between the two polarization modes of the fiber, analogous to the round trip delay in an etalon. For a polarization extinction of 100:1 one finds that AM originating from this effect can be as large as 40% peak-to-peak. This effect is illustrated in the calculation of Fig. 1, where both the spectral and temporal behavior is shown for propagation of 100 GHz of FM bandwidth through a 1 m fiber which has polarization extinction of 250:1. In addition, as is shown in Fig. 1, the amount of temporal AM is strongly dependent on the relative phase between the two modes of the fiber, which is sensitive to a number of environmental variables. This effect is further exacerbated by the connection of many such fiber components in series. Analysis and approaches to minimizing this and the other various effects which lead to AM are presented.

This work was performed under the auspices of the U. S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

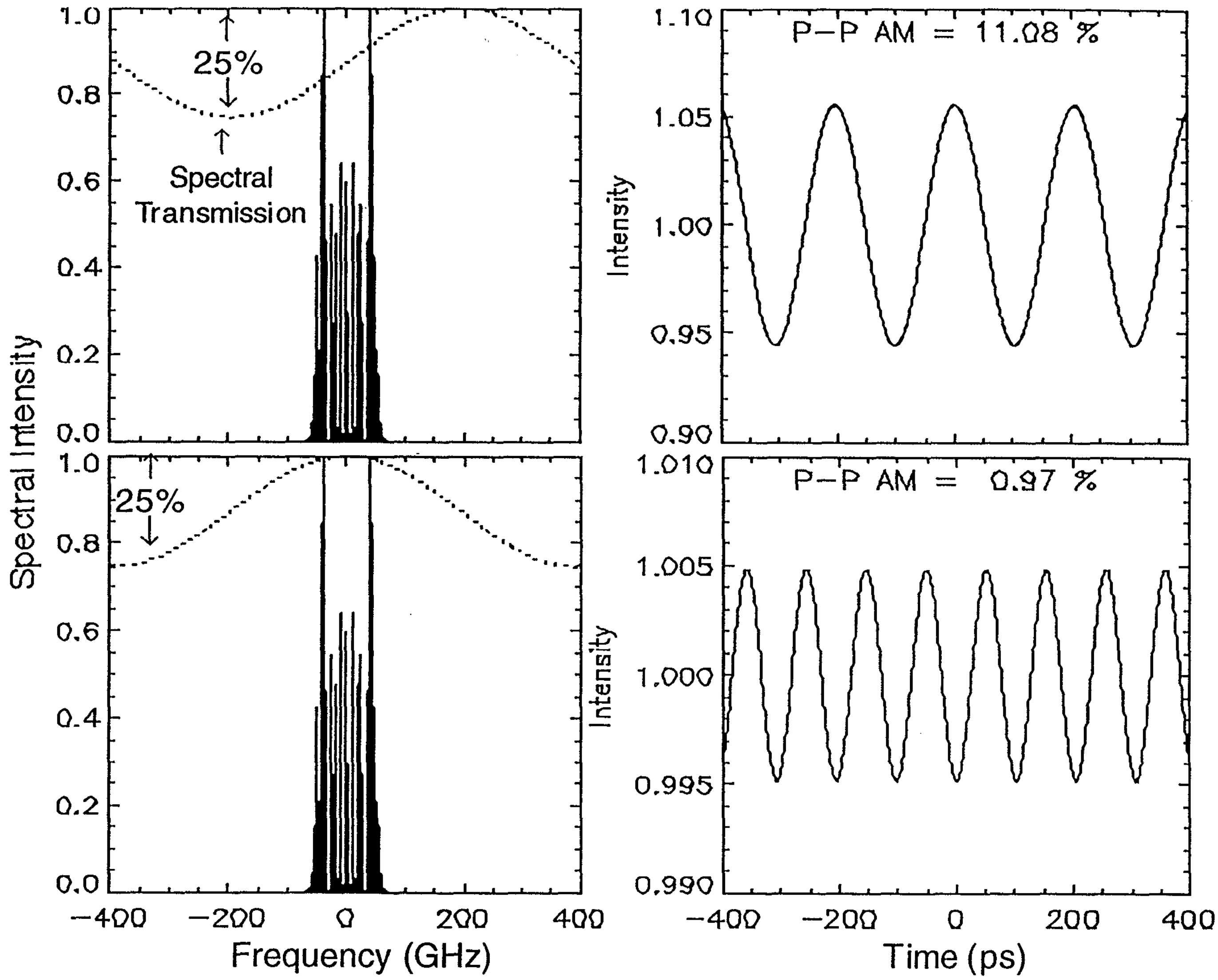

Figure 1: Spectral and temporal behavior of FM light of bandwidth 100 GHz after transmission through 1 m of birefringent fiber, where the polarization extinction between the two modes is 250:1. The top plots show the case where the two modes are 90° out of phase, and the bottom where they are in phase. The dotted curves show the spectral transmission through the fiber in the primary polarization.

Implementation of Smoothing by Spectral Dispersion on Beamlet and NIF

Joshua E. Rothenberg, Bryan D. Moran, Paul J. Wegner, and Tim L. Weiland

Lawrence Livermore National Laboratory, L-439,P. O. Box 808, Livermore, CA 94551
Telephone: (510) 423-8613 , FAX: (510) 422-5537 , Email: JR1 @ LLNL.GOV

ABSTRACT:

The National Ignition Facility (NIF) has been designed such that it will have the capability for both the direct and indirect drive approaches to ICF. In either approach it is necessary to insure that the target is illuminated with a very uniform beam. The beam smoothing method chosen for NIF is smoothing by spectral dispersion (SSD)[1] used in conjunction with a kinoform phase plate. The phase plate generates a speckle pattern with a precisely controlled envelope, and the spectral dispersion of bandwidth imposed on the driver beam causes a rapid fluctuation in this speckle pattern. The impact of the high spatial frequencies of the speckle ("hot spots") on the target is ameliorated by the averaging of multiple uncorrelated speckle patterns over some effective integration time.

In an ongoing set of experiments, one dimensional SSD has been implemented and characterized on Beamlet. Measurements are performed to verify the spectral, spatial, and temporal characteristics of both the 1ω and the 3ω beams. A number of key issues affect the extent to which the laser performance is degraded from the implementation of SSD. This is of particular importance to the NIF, as SSD has not been implemented previously in a multipass amplifier architecture. One expects that near field modulation owing to SSD may result from a number of sources, such as group velocity dispersion, nonuniform spectral gain or loss, clipping in the pinholes, and frequency conversion. Frequency conversion is of particular concern, since the baseline of NIF requires very high conversion efficiency, and SSD bandwidth is expected to cause a significant decrease. In addition the divergence imposed by SSD will broaden the focal spot, which may be a limiting factor in the passage of the focused beam through the laser entrance hole of the hohlraum in the indirect drive approach. The SSD divergence can be minimized by using a very high frequency of modulation for generation of the bandwidth. In this investigation an integrated-optic electrooptic modulator, capable of FM at a modulation frequency of up to 20 GHz, provides bandwidth of up to 5 Å in the IR, and a grating provides the SSD angular divergence of up to 50 μrad (measured in the main laser amplifier cavity). With these parameters, it is expected that an RMS intensity smoothness below ~20% will be obtained in the far field. The results of characterization of both the near and far field beam , as well as 1ω to 3ω conversion efficiency will be presented.

This work was performed under the auspices of the U. S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

Reference:

1. S. Skupsky, *et al*, J. Appl. Phys. **66**, 3456 (1989).

Focal Spot Conditioning for Indirect Drive on NIF

Joshua E. Rothenberg, Shamasundar N. Dixit, and Wade H. Williams

Lawrence Livermore National Laboratory, L-439,P. O. Box 808, Livermore, CA 94551
Telephone: (510) 423-8613 , FAX: (510) 422-5537 , Email: JR1 @ LLNL.GOV

ABSTRACT:

The indirect drive approach to ICF requires a carefully controlled focal spot to ensure minimal scattering of the focused beam owing to laser plasma instabilities and adequate clearance as the beam passes through the laser entrance hole (LEH) in the hohlraum. The limit of the plasma instabilities leads to a requirement on the maximum allowable focal intensity, and thus one desires the largest flat-top spot while still clearing the LEH. The requirement to clear the LEH leads to a maximum allowable intensity in the wings of the central spot. A kinoform phase plate (KPP) can be used to accurately form the central (elliptical) spot shape with minimal wings, however aberrations in the laser amplifier and nonlinear effects cause a large increase in the wings of this ideal spot. Therefore, the margin for the maximum power deliverable to target can be significantly enhanced by improving the quality of the focus and thus reducing these wings.

Calculations are presented which show that the large spread of the NIF focal spot wings owing to nonlinear effects is almost entirely due to 'whole beam' self-focusing (the nonlinear phase shift which appears on the edge of the near field beam). This nonlinear effect can be nearly eliminated by a static phase plate which applies a phase correction (assumed to follow an error function shape) to the edge of the 3ω beam. The results indicate that the increased wings are driven mostly by nonlinear effects in the 1ω beam section. In these simulations it is also found that the adverse effect of this phase corrector on the focal spot in the low power pulse foot (when there is no nonlinear phase shift) is minimal. This favorable result occurs because the beam becomes larger as the pulse power increases, owing to amplifier saturation. As a result, the beam in the pulse foot 'misses' most of the edge gradient in the static phase corrector plate.

In spite of the improvement in the wings by this phase corrector, the calculated focal spot still cannot simultaneously meet the desired central and wing intensity criteria. To further reduce the wings requires improvement in the residual cumulative aberrations in the 1ω laser section. An attractive technique to accomplish this is the use of a phase corrector plate in the laser front end. This plate must be customized for each beamline and precisely aligned, however when properly implemented the focal spot wings are reduced to a level which meets the desired specifications at the LEH (see Fig. 1). An analysis of the effects of the KPP and these phase correction methods on the focal spot and their relation to the target physics specifications will be presented.

This work was performed under the auspices of the U. S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

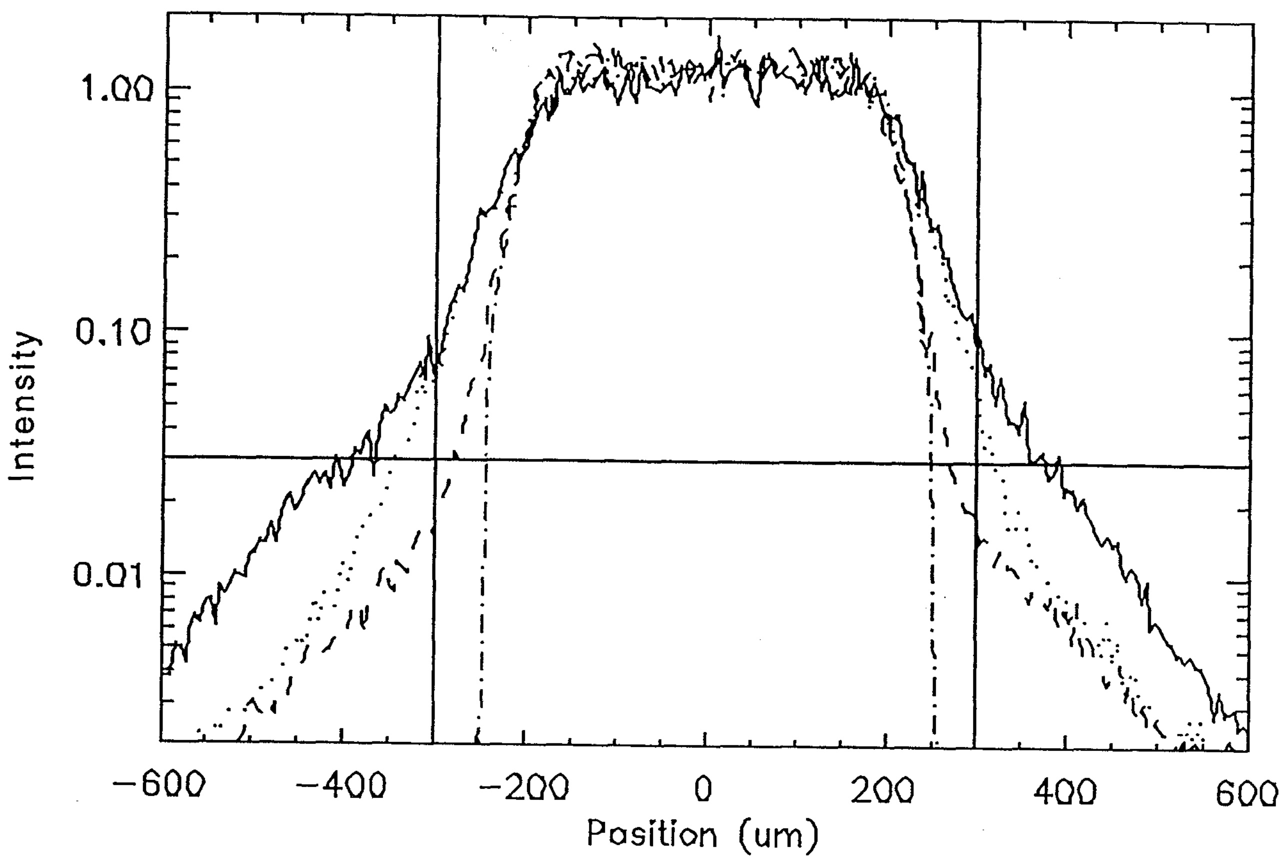

Figure 1: Intensity profile along the minor axis of the elliptical NIF focal spot. Shown without any correction (solid), with a nonlinear phase corrector (dots), with an aberration corrector in the laser front end (dash), and the ideal spot generated by the KPP (dot-dash). The solid guide lines show the desired maximum wing intensity at ± 300 μm radius.

Focal Spot Conditioning for Indirect and Direct Drive on NIF

Joshua E. Rothenberg, Shamasundar N. Dixit, Steven W. Haan,
Stephen M. Pollaine, Wade H. Williams and Jerome M. Auerbach

Lawrence Livermore National Laboratory, L-439,P. O. Box 808, Livermore, CA 94551
Telephone: (510) 423-8613 , FAX: (510) 422-5537 , Email: JR1 @ LLNL.GOV

ABSTRACT:

Both direct and indirect drive approaches to ICF require a carefully controlled focal spot. For direct drive, the precision shaping of the focal spot is required to maintain accurate beam balance. For indirect drive one must ensure adequate clearance as the beam passes through the laser entrance hole (LEH) in the hohlraum, while minimizing scattering from laser plasma instabilities. This leads to a requirement on the maximum allowable focal intensity, and thus one desires the largest flat-top spot with minimal wings to clear the LEH. A kinoform phase plate (KPP) can be used to accurately form the central (elliptical) spot shape with minimal wings, however aberrations in the laser amplifier and nonlinear effects cause a large increase in the wings of this ideal spot.

Calculations are presented which show that the large spread of the NIF focal spot wings owing to nonlinear effects is almost entirely due to 'whole beam' self-focusing (the nonlinear phase shift which appears on the edge of the near field beam). This nonlinear effect can be nearly eliminated by a static phase plate which applies a phase correction to the edge of the 3ω beam.

To further reduce the wings of the focal spot requires improvement in the residual cumulative aberrations in the 1ω laser section. An attractive technique to accomplish this is the use of a phase corrector plate in the laser front end. This plate must be customized for each beam line and precisely aligned, however when properly implemented the focal spot wings are reduced to a level which meets the desired specifications at the LEH. An analysis of the effects of the KPP and these phase correction methods on the focal spot and their relation to the target physics specifications will be presented.

This work was performed under the auspices of the U. S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

An overview of recent KDP damage experiments and implications for NIF tripler performance

Mike Runkel
Lawrence Livermore National Laboratory
P.O. Box 808, L-250
Livermore, CA 94550
Phone: (510)-424-2210
FAX: (510)-422-3361

Abstract

Considerable attention has been paid over the years to the problem of growing high purity KDP and KD*P to meet damage threshold requirements of ICF lasers at LLNL. The maximum fluence requirement for KD*P triplers on the National Ignition Facility (NIF) is 14.3 J/cm^2 at 351 nm in a 3 ns pulse. Currently KD*P (conventional or rapid grown) cannot meet this requirement without laser (pre)conditioning. In this overview, recent experiments to understand laser conditioning and damage phenomena in KDP and KD*P will be discussed. These experiments have lead to a fundamental revision of damage test methods and test result interpretation. In particular, the concept of a damage threshold has given way to measuring performance by damage distributions using millimeter sized beams. This has become possible through the application of automated test technology. In addition, centimeter size beams from multijoule lasers have been used to study stepwise laser conditioning in KDP. These tests have shown that an increase in the damage threshold of ~1.5X is attainable with 8-12 shots of increasing fluence. In addition, the damage density (pinpoints/mm^3) evolves exponentially as a function of local fluence and once formed, the micron sized bulk pinpoints remain stable against increases in local fluence.

The information obtained from damage distributions and conditioning studies has been used with model NIF spatial profiles to determine the probability of damage and the local pinpoint density generated in a tripler. Calculations based on test data have shown that for well conditioned, high quality KD*P the damage probability is less than 3%. Furthermore, the fluence profiles expected on NIF lead to only small numbers of generated pinpoints.

To check the validity of the results, the 37 cm KD*P tripler from the Beamlet laser was mapped for damage. The inspection revealed pinpoint densities of the order predicted by the damage evolution calculations.

*Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-ENG-48.

Solid State Lasers For application (SSLA)
to Inertial Confinement fusion (ICF)

Third Annual International Conference

June 7-12, 1998
Monterey Conference Center
Monterey, California

LMJ TARGET AREA DESIGN AND ENGINEERING PHYSICS INSIDE THE TARGET CHAMBER

Daniel Schirmann, Luc Bianchi, Roger Courchinoux, Henry Patrick Jacquet, François Jequier, Anne Fornier, A. Geille, Jean Claude Gomme, Thierry Lonjaret, Gerard Sibille, Jean Pierre Thebault

Commissariat à l'Energie Atomique, Centre d'Etudes de Bruyeres le Châtel, BP 12
91680 Bruyeres le Châtel Cedex (F)

The LMJ target chamber and its equipment are designed to withstand the maximum threats imposed by large emissions of neutrons, x-rays and debris due to the explosion of 20 MJ high fusion yield targets.

The x-ray effects on the debris shields and the first wall and the inserted instruments are detailed. We show how the first wall has to be protected by refractive materials to avoid its vaporization and, as a consequence, final optics damages. We show how the instruments close to the target have in addition to be protected by shock absorber structures to withstand the high impulse intensity deposited by x-ray and ions.

We also show that high velocity shrapnels can be generated by neutron, x-ray and ion depositions in materials close to the target, so that the target environment has to be designed to minimize their effects in particular on the final optics.

Experiments conducted as well as on Phebus laser facility at Limeil or on electric plasma guns at Cesta are used to validate most of our prediction models, to study the behavior of first wall material candidates, the generation of the shrapnels and their effects to first wall materials, final optics and also to validate shock absorber structures allowing to protect the instruments close to the target.

The design status of the target area is also presented.

D. Schirmann
CEA Bruyères le Châtel
DP2I / LMJ
91680 Bruyères le Châtel Cedex (F)
Tel : 1 69 26 53 66
Fax : 1 69 26 70 75
e-mail : schirman@bruyeres.cea.fr

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TU1B-4

Importance of Control of Inter-layer Mixing by Surface Chemistry and Analysis by Surface Science To Minimise (and Engineer The Nature Of) Laser-Induced Damage In Multi-Layer Optics

Rita Badheka, David Grosso, Paul A. Sermon* and Mariana S.W.Vong

Department of Chemistry, University of Surrey, Guildford, GU2 5XH, UK
and
CSMA. Manchester, UK

SiO_2-ZrO_2 3ω mirrpots composed of multi-layer stacks with up to 20 low-index/high-index pairs have been prepared upon fused silica substrates by acid and base catalysed sol-gel chemistry.

Reflectance characteristics have been compared with theoretical predictions based upon Film 2000 software. The stacks have been depth profiled by

neutron reflectance,
O1s binding energies with argon ion etching, and
dynamic secondary ion mass spectrometry

Such results correlate well with the types of damage site seen by

atomic force microscopy,
scanning electron microscopy-EDAX,
micro-scanning Auger, and
FT infra-red and Raman spectro-microscopy

when the mirrors are subject to laser treatment at progressively higher energies. Such data are reported in detail and methods of control of levels of interlayer mixing are suggested for optimum mirror properties.

Points of contact: tel 044-1483-259593; fax 044-1483-259514
p.sermon@surrey.ac.uk;

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BLASTSHIELD DESIGN FOR LMJ AMPLIFIERS

T. Berthier,* O. Bonville,* B. Bicrel,* D. Estéban,* E. Grebot,*
JH. Quessada,***, X. Maille,* P. Manac'h,* J. Morvan,***
JC. Nault,* P. Patelli,** S. Seznec*

*CEA Limeil-Valenton, DRIF/DLP 94195 Villeneuve St-Georges, France
**CEA CESTA, DRIF/DLP, BP2 33114 Le Barp, France
***CEA CESTA/DEV

The CEA Limeil-Valenton Inertial Confinement Fusion (ICF) program is currently addressing the critical physics and technology issues for building and exploiting Nd^{3+} high power megajoule laser. The French Megajoule laser (LMJ) will include 240 40 by 40cm^2 beams into 30 laser bundles of 4x2 beams each. Each bundle is equipped by eighteen 4x2 flashlamp pumped segmented amplifier modules allowing simultaneously the amplification of 8 laser pulses from a few hundreds of millijoules to about 20 kJ.

Each amplifier module receives two 4x1 laser glass slabs cassettes and three flashlamps cassettes. Slabs and flashlamps cassettes are separated by blastshields. Blastshields are made of a 2x 0,7 m^2 sheet of high transmission glass. Their goal is to maintain a very high cleanliness level (class 10) into the slab cassette but also to protect slabs in case of flashlamp explosion. Recent experiments showed that current 4.3 mm-bore diameter two meter long flashlamps could explode under standard 360µs-13kJ electrical conditions. Explosions were due to defects in the quartz tube of the flashlamp or to electrical arcs in the connector base. Such problems have to be solved for operating LMJ in good conditions. CEA and vendors are in the process to improve the flashlamp design and fabrication but such event could happen anyway to one of the 10800 LMJ flashlamps. We decided to evaluate the impact of an explosion on the current 6 mm thick blastshields and noticed that they could not resist to any of the two different flashlamp explosion modes. Such blastshield failure in LMJ would concern the operating costs but also laser availability.

So we have conducted experiments to test new materials (armoured glass) and new assemblies (laminated glass) for blastshields.

In a first experiment, we have tried to understand the mechanism of a flashlamp blow up to quantify the corresponding energy. Flashlamps with electrical isolation defect or tube defect (weakened glass) have been used to explode at every shot. A fast camera (40 000 images/s) and Xray radiographs were used to record the explosion.

In a second time, the speed of a thin sheet of metal placed on a dummy blastshield was determined by Interferometry Doppler Laser measurements.

Results of these two experiments allowed us to evaluate the size and speed of glass parts, and the pressure during explosion.

UV resistance tests were conducted with different materials, up to 1500 shots in a flashlamps test facility. Four different blastshields were produced in selected materials, and tested during a flashlamp explosion. After these experiments, a glass was selected for LMJ blastshields. We now plan to expose a sample of this glass to lifetime test in a small flashlamp facility (10 000 to 15 000 shots). This lifetime test is necessary to fully validate the selected glass and ensure a high availability of laser facility.

GROWTH OF BIG KDP CRYSTALS AT THE FORM OF PLATES.

V.A.TATARTCHENKO - R&D project Manager
CRISMATEC, 104 Route de Larchant - BP 521
77794 Nemours Cédex - France
Tel : (33) 1 64 45 10 10 - Fax : (33) 1 64 45 10 02

KDP and DKDP single crystals are used for effective control of laser emission properties (intensity, polarization, wavelength, and alignment) especially in cases where the size of cross section of the light beam is tens of centimeters. For instance, for the NIF and LMJ facilities, frequency conversion plates and Pockels cells with the dimensions 41x41x1cm are needed. In this case, there is no alternative to the KDP and DKDP crystals grown from the aqueous solution.

At present there is only one technique that allowed the growth of some KDP crystals of sizes sufficient to cut plates of dimensions 41x41 cm [1]. But we need a very big crystal (50x50x50cm) in order be able to cut from it only few plates of 1cm thickness. This means that only 5-10% of crystal volume can be used for plate production and as a result the price of plates, especially for DKDP, will be very high.

For the past two years CRISMATEC and CEA have been developing a technique of crystal growth for the KDP plates of orientation we need. The idea of our technique is the following : Let us assume that we need a frequency converter of a definate type. We cut the seed in the form of small plate 10x10x4 mm. A crystallographic orientation of surface of the seed coincides with one of the converter. We glue the seed on the horizontal platform rotating in the aqueous solution of KDP salt with an equilibrium temperature of 50 - 70 °C. A three dimensional growth of crystal begins when we lower the temperature of the solution. There is second platform parallel to the first one that is located on a platform 25 - 40 mm higher. When the growing crystal approaches the higher platform, vertical growth comes to a halt and two dimensional growth begins.

As a result of our experiments, we have achieved two types of frequency converter (first and second type) orientation KDP plates. The biggest plate (frequency converter of the first type) has a form of rhombi with the thickness of 40mm and a larger diagonal of 330mm. As a rule, an average speed of growth was 10 mm/day. Some of these plates do not have any visible defects. CEA deposed a patent No 9707835000 dated on 06/24/1997.

Work performed under the auspices of the Commissariat à l'Energie Atomique (France) by CRISMATEC under Contract No.3792/LV.

Reference:

1.N.P.Zaitseva, J.J.De Yoreo, M.R.Dehaven et al, Journal of Crystal Growth, 180 (1997) 255 - 262.

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W1B-1

ISA JOBIN YVON-SPEX HORIBA

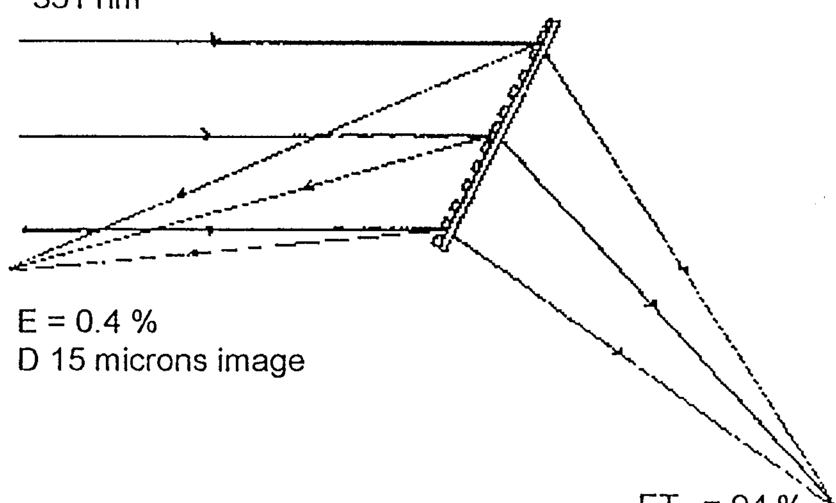
FOCUSING TRANSMISSION GRATINGS

FOR HIGH ENERGY LASERS

Bruno TOUZET, Jean FLAMAND, Alain THEVENON, Viviane MILLET, Francis BONNEMASON, Philippe GACOIN, Benoit DEVILLE

JOBIN-YVON division of INSTRUMENTS SA
16-18 rue du Canal - 91165 Longjumeau Cedex - France
Tel : 33 1 64 54 13 00 - Fax : 33 1 69 09 93 19
E-mail : bruno _touzet@isajy.com

Diffractive optics is known as an excellent optical component to focus light beams. Engraved directly within pure fused silica a focusing transmission grating withstands very high energy laser beam in visible and UV range. It offers the possibility to get a well focused sampling beam in addition to the high efficiency transmission capabilities. For quantity production new technologies are emerging to produce these components at reduced cost.



In this paper, we will describe the manufacturing techniques used to produce the focusing transmission gratings, the performances recently obtained and the benefits of using such components.

Described manufacturing techniques include :

. Calculation of variable spacing of grooves and curvature of grooves to focus the laser beam (diffraction limited)

. Calculation of required groove profile to get the high transmission efficiency

. Holographic recording and ion etching process

. Quantity production process

Typical performances measured on recently produced focusing transmission gratings will be described :

. Transmission efficiency : up to 92% to 94% on polarization s or p at wavelength of use : 1.053 micron (1ε) or 351 nm (3ε)

. Image spot size dimension : 20 microns

. Sampling efficiency : 0.4 %

. Damage threshold : same as super polished fused silica windows

Some benefits, among many others, of focusing transmission gratings will be enlighted :

. A single optical component performs 3 jobs :

- Spectral dispersion (separation of the 3 harmonics)
- Focusing properties (as good as an aspheric lens)
- Sampling capabilities

. Dispersion can be adjusted according to number of grooves (up to 2800 g/mm)

. Minimum thickness of glass required (by example 10 mm thickness of glass for 500 mm size of component)

. Large size possible (500 x 500 mm)

. Cost effective and good performance consistancy when produced by quantity

In conclusion this new technology to manufacture transmission focusing gratings performs efficiently to focus very high energy lasers

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W4B-5

Start-up plan for the first NIF laser bundle : transition from single Beamlet prototype to 192-beamline laser facility

B.M. Van Wonterghem, M.A. Lane, D.R. Speck, D. Tiszauer,
P.J. Wegner, S.C. Burkhart, L. Hackel

University of California
Lawrence Livermore National Laboratory
PO Box 5508, L-493 Livermore, CA 94551-9900
(510) 423-9494 / FAX (510) 423-4606

ABSTRACT

The compact laser design and the extensive use of optical component assemblies as line replaceable units (LRU) are essential to achieve the cost efficiency of the National Ignition Facility design. This design philosophy change requires a new approach to start-up operation of a 192 high energy beam line laser compared to existing fusion laser facilities. The main difference is the limited access and on-line verification and maintenance capability, requiring extensive component verification and alignment in off-line facilities such as the Optics Assembly Building.

We are developing a detailed plan for the start-up plan of the NIF facility, based on systematic off-line component and LRU verification tests, followed by a well defined set of operational test procedures to verify integrated performance. Laser performance parameters of individual beam lines will be verified using a precision diagnostic system located in the NIF switchyard. The LRU based architecture can accommodate the use of in-line diagnostic LRU's for calibration and performance testing at critical points during start-up. X-ray diagnostics will be used to verify multiple beam on target performance using diagnostic disk target shots in the NIF target chamber.

We will discuss the detailed plan for the start-up of the first bundle of 8 beam lines, a laser system by itself similar in size and complexity to the LLNL Nova laser and the application of lessons learned from start-up and operation of the Beamlet prototype beam line during the last 4 years. Experience on the first bundle of beams is required to optimize the start-up procedures to expeditiously deliver operating laser bundles at the rate of one bundle per month to complete the NIF facility.

This work was performed under the auspices of the United States Department of Energy by Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.

Control of the amplification of large band amplitude modulated pulses in Nd-glass amplifier chain.

L.Videau(1) , J.Garnier(2) , E.Bar(1), C.Rouyer(1), C.Gouedard(1), A.Migus(3).

(1) *Commissariat à l'Energie Atomique Centre d'Etudes de Limeil-Valenton.*
94195. Villeneuve Saint-Georges , Cedex , France
Tél : (33) 1-45-95-65-80 Fax (33) 1-43-86-74-07
e-mail : videau@limeil.cea.fr

(2) *Centre de Mathématiques Appliquées, Centre National de la Recherche Scientifique*
Ecole Polytechnique . 91128 . Palaiseau , Cedex France

(3) *Laboratoire pour L'Utilisation des Lasers Intenses, Centre National de la Recherche Scientifique*
Unité mixte de Recherche 100, Ecole Polytechnique . 91128 Palaiseau Cedex , France

Abstract

The development of the coming generation of Megajoule-class laser requires optical smoothing to obtain both a focal spot large enough and a good uniformity. Different optical smoothing techniques have been proposed and experimented, such as Smoothing by Optical Fiber (S.O.F.) [1] and Smoothing by Spectral Dispersion (S.S.D.) [2]. S.O.F. seems to be an efficient method when it deals with asymptotic contrast, shape and control of the focal spot, or smoothing of low spatial frequencies. But, earlier experiences with S.O.F. technique have shown a strong limitation in term of the amplification performances [3] .

In this paper, we will present recent results obtained on the backlighter beamline of the Phebus facility which delivers up to 1.5 kJ at 1053 nm on a 19 cm diameter beam in a 1.3 ns square pulse. Figure 1 shows the output energy as a function of input energy for two configurations. The upper curve corresponds to a monochromatic pulse, the lower one to a spatially coherent broadband pulse ($\Delta\lambda$=1.2 nm). It shows a loss of 10% for the performance in the latter case. Figure 2 presents the observed output amplified spectra vs output energy. The main conclusion is that gain broadening takes over the expected gain narrowing effect. To explain these data, we have developed a stochastic

model of incoherent field amplification in presence of Kerr non-linearity which induces a large break-up integral B[4]. Results in term of energy loss correspond in our experimental case to a decrease of 10% for the maximum input of fig.1, in good agreement with the experimental data.

Figure 3 shows spatially incoherent pulse amplification compared to spatially coherent broadband pulses. For incoherent pulses obtained by the SOF technique, we have two experimental schemes. One set of data (circles) corresponds to the standard chain with regular hole filters, the second one without hole filters (squares). This shows that hole filters are responsible for a 10 % decrease of output energy when using smoothing compared to broadband pulses. The important observation is that without hole filters, we did obtain the same output energy with and without smoothing for broadband pulses. The analogy with the previous spectral case is obvious : the B-integral expands the spatial spectrum the same way it expands the temporal spectrum, the gain filtering being the equivalent of pinholes.

As a conclusion, nonlinear effects involved in incoherent pulses amplification are well now understood. Different techniques which can be applied to circumvent the above limitations will be discussed such as the injection of an optimized narrower spectrum and the use of the nonlinear B broadening or/and the use of larger and a beam with a smaller number of modes.

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[2] *'Improved laser-beam uniformity using the angular dispersion of frequency-modulated light'*
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[3] *'Optical smoothing of the high power Phebus Nd-glass laser using the multimode optical fiber technique'*
D.Veron et al Optics Communication 97 259-271 ,1996

[4] *'Amplification of broadband incoherent light in homogeneously broadband media in presence of Kerr nonlinearity'*
J.Garnier et al. J.O.S.A. B 14 (10) 1997, 2563

Figure captions

Fig.1 : Experimental energy output as a function of mid-chain energy input, in the case of a monochromatic pulse (circles) and a broadband pulse of bandwidth (FWHM) 1.2 nm (squares).

Fig.2 : Experimental spectral broadening with a broadband pulse of bandwidth (FWHM) 1.2 nm.

Fig.3 : Experimental energy output as a function of mid-chain energy input, in the case of a broadband pulse of bandwidth (FWHM) 1,2 nm (triangles), smoothed pulses using hole filters (circles) and smoothed pulses not using hole filters (squares).

figure 1

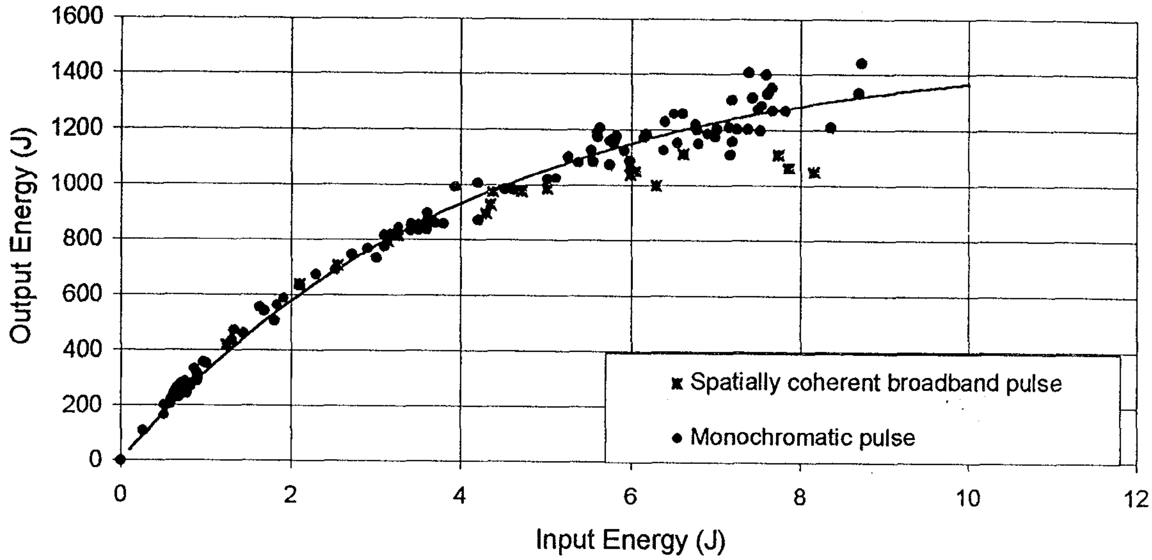


figure 2

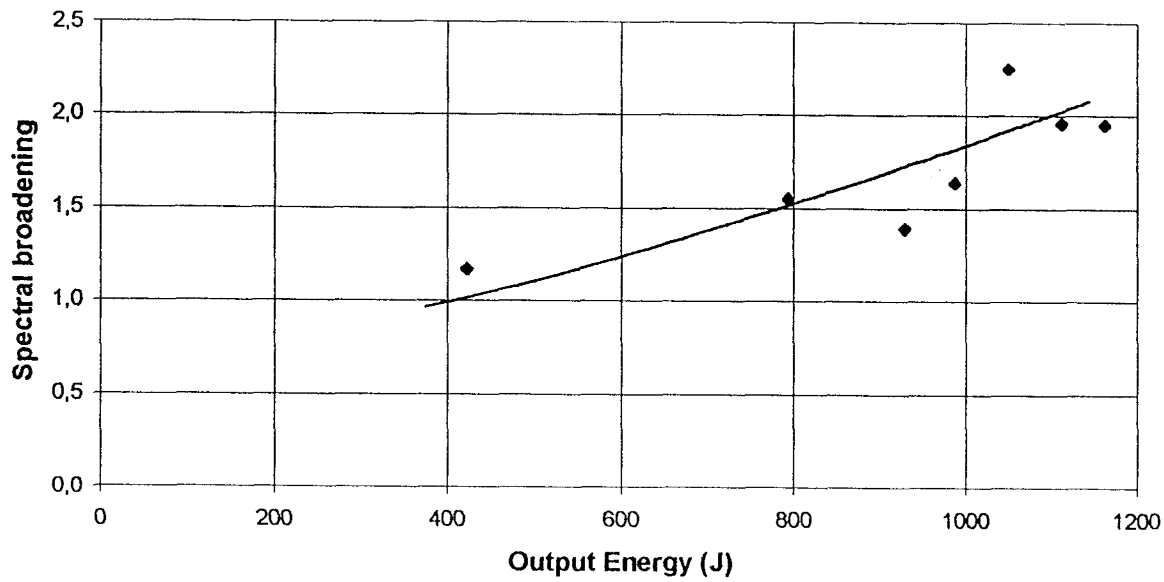
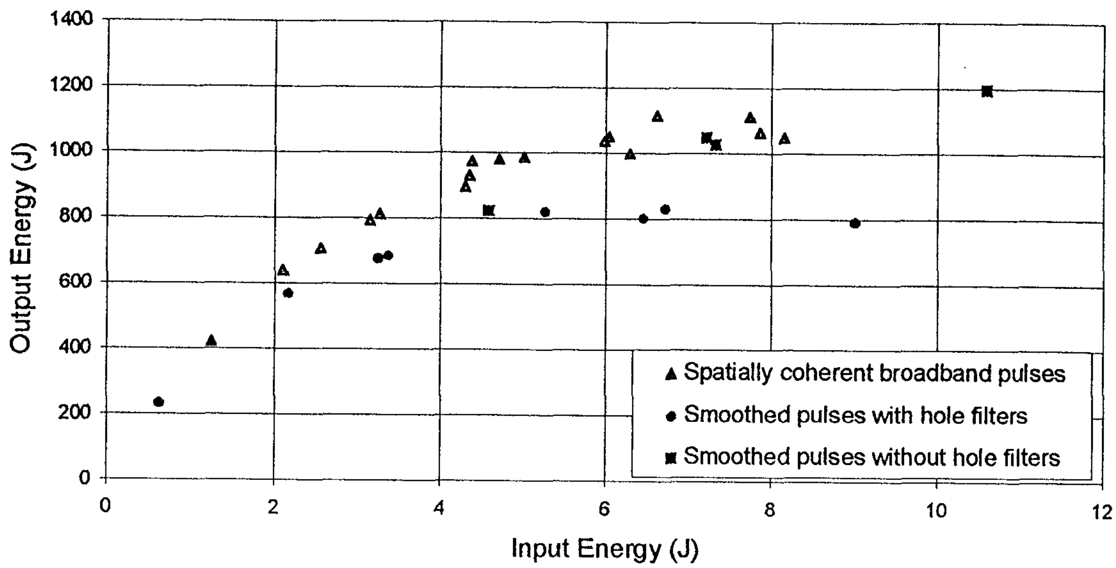


figure 3



1400
1200
1000
800
600
400
200
0
Output Energy (J)
0
2
4
6
8
10
12
Input Energy (J)
Spatially coherent broadband pulses
Smoothed pulses with hole filters
Smoothed pulses without hole filters

Hot spot motion for SSD when using sinusoidal phase modulation.

L.Videau(1), J.Garnier(2), C.Rouyer(1), A.Migus(3).

(1) *Commissariat à l'Energie Atomique Centre d'Etudes de Limeil-Valenton.*
94195. Villeneuve Saint-Georges Cedex France
Tél : (33) 1-45-95-65-80 Fax (33) 1-43-86-74-07
e-mail : videau@limeil.cea.fr

(2) *Centre de Mathématiques Appliquées, Centre National de la Recherche Scientifique*
Ecole Polytechnique . 91128 . Palaiseau Cedex France

(3) *Laboratoire pour L'Utilisation des Lasers Intenses, Centre National de la Recherche Scientifique*
Unité mixte de Recherche 100, Ecole Polytechnique . 91128 Palaiseau Cedex France

Abstract

Smoothing techniques are important for Ignition Confinement Fusion in order to reduce instabilities in the plasma interaction. For I.C.F. direct drive scheme dominated by the control of hydrodynamical instabilities, the most relevant parameters are the integrated contrast and the smoothing of spatial frequencies. Many previous studies mostly dealt with techniques improving these parameters [1,2].

Nevertheless, future ICF configurations (LMJ and NIF) will use the indirect drive scheme which allows a more symmetric compression. Because of the X-ray conversion stage, the optical low contrast is no more the most strongest constraint. However, it remains the issue that high laser intensities induce parametric instabilities in the extended window and in the hohlraum gas. The resulting parametric instabilities are filamentation, Brillouin and Raman effects which may be responsible for energetic losses as high as 30 %.

In case of smoothing technique involving moving speckles (SSD [3], ISI [4], SOF [2]), the dynamic behavior is governed by the laser coherence time τ_c (inverse of the spectrum). The optimized configuration would correspond to a τ_c smaller than the characteristic instability growth rates, the integrated contrast being not the most relevant parameter.

Many works are now dealing with the effects of smoothing techniques used to reducing parametric instabilities. Very often theoretical papers consider speckle patterns as hot spots moving in the forward direction [5].

In this work we studied the motion of speckles in different 1D types of SSD techniques, in particular in order to check the validity of the moving hot spot approximation. The case we analyze is 1D-SSD [5] and longitudinal 1D-SSD. This latter technique involves a focusing grating which can be approximated as a Fresnel lens and induces a longitudinal time delay. For both methods, we assume sinusoidal phase modulation.

We have developed a statistical approach which in particular allows to follow the correlation maximum in space as a function of time. We find that in the range of a few τ_c, the correlation maximum shifts in space but remains very high, which means that the hot spots are moving. More surprisingly results show that this motion may appear as having negative speeds or speeds larger than light velocity. The relevant parameters are the frequency modulation ν_m, the modulation depth β and the speckle size. For a given spectrum (equal to the product $\beta\ \nu_m$) different speed histograms could appear. So, the choice of the best couple of parameters (ν_m , β) is crucial for reducing the interaction length between the laser and parametric instabilities. This statistical analysis is then compared and found in good agreements with numerical simulations.

We will also discuss different methods which allow to induce a fast decrease of the correlation amplitude which is equivalent to canceling the motion of the speckle spots.

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M3-1

FINAL OPTICS DESIGN FOR THE LASER MEGAJOULE

Alain Adolf, Alain Boscheron, Arnaud Dulac, Eric Journot

Commissariat à l'Énergie Atomique
Centre de Limeil-Valenton, 94195 Villeneuve St. Georges Cedex, France
Tél 33 1 45 95 61 01 Fax 33 1 43 86 74 06
e-mail Adolfalain@aol.com

Abstract:

We present the final optics design of the Laser Megajoule using high efficiency transmitting gratings at 1053 nm and 351 nm for broadband tripling, wavelength filtering, laser diagnostics sampling and focusing on target.

Summary:

The final optics assembly is one of the most critical components of the Megajoule laser to achieve inertial confinement fusion.

The final optics have primarily to convert the amplified IR beam to the third harmonic and to focus the converted UV beam on the target, taking into account the ability for beam smoothing on target. Optimal system design requires also to protect the target and the plasma diagnostics by filtering the unconverted light (at 1053 nm and 526.5 nm), to deliver a high quality sample laser diagnostic beam for precision metrology, to protect most of the optical and mechanical parts from the neutron emission by the target and from the backscattered UV light. Our original design based on a pair of transmission diffractive elements successfully achieve all these functions.

The laser Megajoule will focus 240 square beams grouped in 60 quads (2 X 2 structure) on a target. The figure 1 shows how one quad works. The system is composed of a first high efficiency diffraction fused silica lamellar transmission grating which deviates the infrared beam 50 degrees away from the incoming direction. Then the beam is converted to the third harmonic by a classical cascaded type I - type II KDP crystal setup. One major constraint in the development of smoothing techniques for increasing the focal spot average uniformity is the narrow spectral bandwidth allowed by the frequency tripling setup. The angular spectral dispersion introduced by the 1053nm grating is used to partially compensate this limitation and authorize broader spectral bandwidth with high conversion efficiency.

Finally, the UV converted beam is deviated 50 degrees back by a second high efficiency diffraction fused silica lamellar transmission grating designed for the UV. This original grating achieve also the focusing function, the separation of the unconverted beams which are transmitted through the grating in beam dumps and the beam sampling for diagnostics. Because we are using a grating, we have diffracted orders in transmission and reflection which contain the same phase information and as shown on Fig. 1 give us a natural focused beam sample.

The high damage threshold required for the LMJ is the main criteria: 25 J/cm^2, 3ns at 1053 nm and 12 J/cm^2, 3ns at 351 nm.

The first experiments show that the damage threshold of etched UV gratings and thick IR holograms is as high than the bare silica plate. Experimental test with sample of 50 mm and 150 mm aperture have demonstrated an average efficiency higher than 90%. A high efficiency 150 mm diameter UV focusing grating is currently used on the backlighter laser chain of the Phebus laser facility (600 J in 1.3 ns square pulse) showing comparable results than with a classical diffraction limited silica focus lens.

A 1/3 scale demonstration experiment is achieved on this facility.

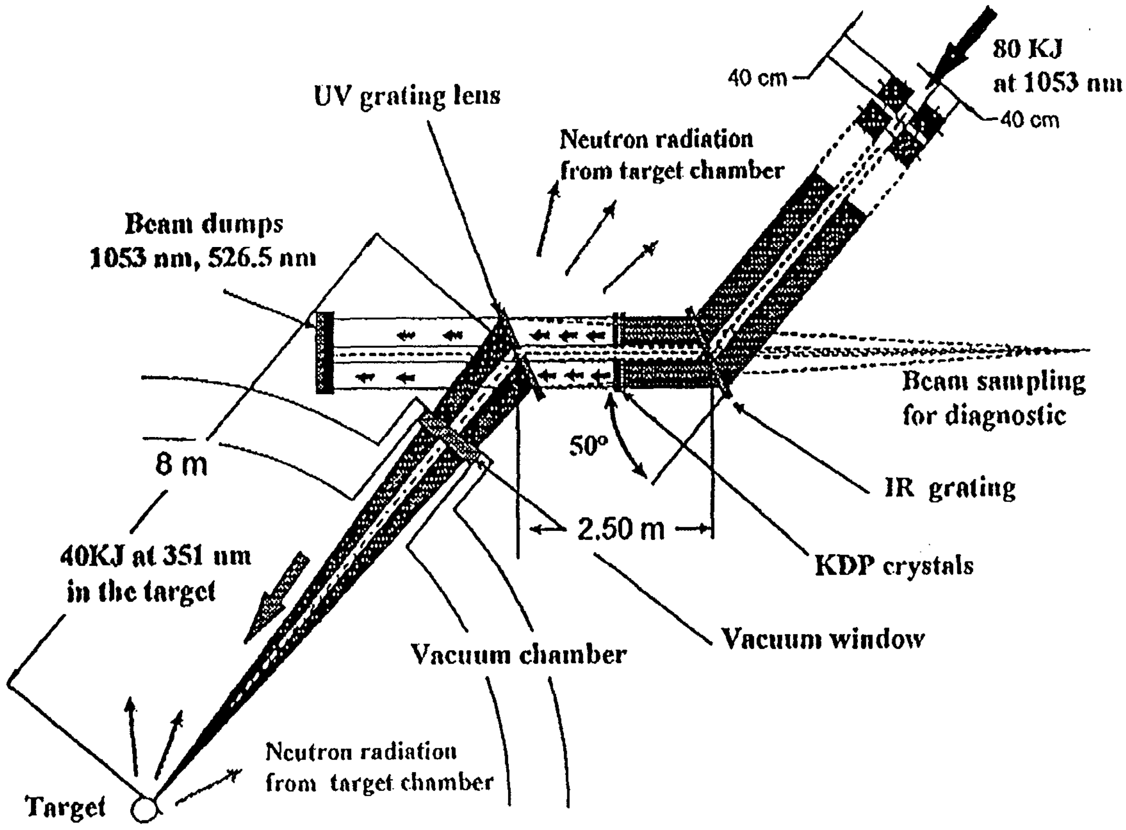

Figure 1 : Final optic design of the LMJ

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LMJ and LIL project status

Michel L. André

Project Leader
Commissariat à l'Energie Atomique
France

LMJ project and its prototype, the Ligne d'Intégration Laser (LIL) have already been presented during the two last meetings in Monterey and Paris. This year we will describe the progress made in the field of building the LIL and developing the technology for production of laser and optical components.

The LIL construction is progressing according to the planning and for example the LIL building has been delivered in time. The first Front End, delivering 1 Joule, has been qualified and will be installed in June in order to start measurements on alignment procedures and supports stability.

Technology development covered the main field of laser glass production, in close connection with the LLNL, and laser glass machining in France. Fabrication of self safe capacitors has been demonstrated within our price goal and production for LIL has been launched. After demonstration at LLNL of the efficiency of growing KDP's with the new fast growing technique a crystal is being built by a French team using the same process. In parallel a KDP machining facility is being installed based on a Moore diamond turning machine.

Detailed amplifier design has started based on measurements made on a French prototype tested in Amplab at LLNL. First amplifiers will be delivered on LIL by mid-1999.

The original focusing system using focusing gratings has been tested on a small scale configuration and preliminary results are validated. A one third (15 cm) scale complete device, including frequency conversion is going to be tested on Phebus before the end of 1998. In parallel a quotation has been requested from several possible vendors all around the world.

Final experiments on LLNL beamlet will take place in June, mainly in the field of 0.35 μm laser damage on optics. These full scale experiments are designated to finally validate measurements made on samples which demonstrated the ability of PVD or Sol-Gel coatings to sustain fluences as high as 25 J/cm2.

In order to facilitate collaboration between US and French laboratories it has been decided to use on LIL and LMJ the same sort of plasma diagnostics inserters.

For the next three years the main events will be the completion of the LIL qualification (mid 2001) and the start of the LMJ building (end of 1999). Most of the progress reported here will be presented during this conference either by oral or poster presentations.

Frequency Converter Development for the National Ignition Facility(*)

P. J. Wegner, J. M. Auerbach, C. E. Barker, S. C. Burkhart, S.A. Couture, J. J. DeYoreo, R. L. Hibbard, L. W. Liou, M. A. Norton, P. A. Whitman, L. A. Hackel

University of California, Lawrence Livermore National Laboratory
P.O. Box 808, L-479, Livermore, CA 94550

The design of the National Ignition Facility (NIF) incorporates a type I/type II third harmonic generator to convert the 1.053-μm fundamental wavelength of the laser amplifier to a wavelength of 0.351 μm for target irradiation. The design of the converter is driven by the requirement to have high conversion efficiency at the peak of a shaped ICF ignition pulse, thus maximizing the delivery of peak power to the target. For example, current specifications call for peak power efficiencies greater than 80% at a nominal 1.053-μm irradiance of 3 GW/cm^2. Conversion efficiencies of 80.6% have been demonstrated on the Beamlet prototype laser, using nominally square-in-time pulses at an aperture size of 32 cm [1]. Development efforts center on improving this result while demonstrating the technology required for scaling to the 40-cm aperture size of NIF.

To understand and control the tolerances in the converter design, we've developed a comprehensive error budget that accounts for effects that are known to influence conversion efficiency, including variations in amplitude and phase of the incident laser pulse, temporal bandwidth of the incident laser pulse, crystal surface figure and stresses, angular alignment errors, Fresnel losses, polarization errors and crystal temperature variations. The error budget provides specifications for the detailed design of the NIF final optics assembly and the fabrication of optical components. Validation is accomplished through both modeling and measurement, including full-scale Beamlet tests of a 37-cm aperture frequency converter in a NIF prototype final optics cell. The prototype cell incorporates full-perimeter clamping to support the crystals, and resides in a vacuum environment as per the NIF design.

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* Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-ENG-48

Wavefront and divergence of the Beamlet prototype laser (*)

P. J. Wegner, M.A. Henesian, J. T. Salmon, T.L. Weiland, W. H. Williams,
B. Van Wonterghem

University of California, Lawrence Livermore National Laboratory
P.O. Box 808, L-479, Livermore, CA 94550

Target requirements for the National Ignition Facility (NIF) set stringent limits on the amount of beam divergence that can be produced by the 1-μm laser driver. Sources of divergence in the driver are well known and fall readily into three categories: thermally induced phase errors related to heat accumulation in the amplifiers, including gas turbulence effects, prompt phase errors related to a rapid deformation of the amplifier slabs during pumping, and static phase errors related to the finishing, mounting and alignment of the optical components. Minimum divergence and maximum laser brightness is achieved when the system is cold and thermally induced phase errors are absent. In this case, performance is limited by the fraction of prompt and static phase errors that remain uncorrected by the wavefront control adaptive optic system.

As part of a recent campaign to optimize the adaptive optics system on the Beamlet prototype laser we have measured the wavefront and the divergence of the cold system under a variety of conditions. Emphasis of the tests was on quantifying best attainable divergence in the angular regime below 20 to 30 μrad to help benchmark propagation models that are used to study wavefront gradient specifications for NIF optical components. Performance was monitored with radial shearing interferometers that measured near-field wavefront at the input and output of the main amplifier with a spatial resolution of 1 cm, and cameras which measured the corresponding intensity distributions in the far field with an angular resolution of 0.3 μrad. Test results showed that the prompt phase errors from amplifier pumping are almost entirely correctable with the adaptive optics system. Static phase errors were only partially correctable, resulting in a residual error of ~1 wave peak to valley, 0.2 waves rms at the output of the laser. Details of the measurements will be discussed and correlated with measurements and modeling of the 1ω and 3ω focal spots.

* Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-ENG-48

THE NIF'S POWER AND ENERGY RATINGS FOR FLAT IN TIME PULSES*

C. Clay Widmayer, Wade H. Williams, Paul A. Renard, and Janice K. Lawson
Lawrence Livermore National Laboratory
P.O. Box 808, L-490, Livermore, California, U.S.A. 94551
(510) 422-9365 FAX (510) 424-5195
clay@nancy.llnl.gov

ABSTRACT

The National Ignition Facility (NIF) power and energy performance for flat temporal output pulses is discussed. Power, energy, and temporal pulse distortion are calculated at key system interfaces. The distribution of power and energy amongst the NIF beams is calculated using a model of 192 independent beamlines. The mean performance of the 192 beamline model is compared to estimates of an average beam obtained using the PROP92 2-D laser propagation code.

*Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

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NIF'S ASSESSMENT OF THE OPTICAL DAMAGE THREAT FOR FLAT IN TIME PULSES*

Michael D. Feit, C. Clay Widmayer, Wade H. Williams, Richard A. Sacks, Paul A. Renard, and Mark A. Henesian
Lawrence Livermore National Laboratory
P.O. Box 808, L-439, Livermore, California, U.S.A. 94551
(510) 422-4128 FAX (510) 422-5537
feit1@llnl.gov

ABSTRACT

High power and high energy flat in time pulses pose a damage threat to the optics in the NIF laser system. In particular the phase noise put on the beam by optical finishing errors and defects in the optics grows as a result of the phenomenon to self-focusing. The control of the damage threat posed by beam break-up and "hot" holographic image formation will be discussed.

The flowdown of the damage threat to the key system components will be presented.

*Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

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TP-NIF

THE NIF'S POWER AND ENERGY RATINGS FOR ICF SHAPED TEMPORAL PULSES*

C. Clay Widmayer, Wade H. Williams, Paul A. Renard, and Janice K. Lawson
Lawrence Livermore National Laboratory
P.O. Box 808, L-490, Livermore, California, U.S.A. 94551
(510) 422-9365 FAX (510) 424-5195
clay@nancy.llnl.gov

ABSTRACT

The National Ignition Facility (NIF) power and energy performance for ICF shaped temporal output pulses is discussed. Power, energy, and temporal pulse distortion are calculated at key system interfaces. The distribution of power and energy amongst the NIF beams is calculated using a model of 192 independent beamlines. The mean performance of the 192 beamline model is compared to estimates of an average beam obtained using the PROP92 2-D laser propagation code.

*Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

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TU/A-3

DEVELOPMENT SYSTEM PERFORMANCE OF THE NIF MASTER OSCILLATOR AND PULSE FORMING NETWORK

Russell Wilcox, Donald Browning, Gary Dreifuerst,
Ernesto Padilla, Frank Penko

Lawrence Livermore National Laboratory
L-490, P.O. Box 808, Livermore, CA 94551-0808
Phone (925) 423-1343 Fax (925) 422-7748
e-mail wilcox2@llnl.gov

The master oscillator and pulse forming system for NIF will be housed in the Master Oscillator Room (MOR) in the NIF facility. The function of the equipment in this room is to deliver low energy temporally shaped and phase modulated pulses to the Preamplifier Modules (PAM's) in the NIF laser bays, which in turn deliver multi-Joule level pulses to the main amplifiers. In designing the MOR equipment, we have had to incorporate many improvements to maintain accurate pulse shaping, amplitude stability, dynamic range, bandwidth, and other parameters which critically affect target performance. During the past year we have assembled a development system which contains all the key components of the MOR design. This paper will review the MOR equipment performance and describe recent improvements.

We have improved and stabilized the oscillator design, using a phase-shifted fiber Bragg grating as the main tuning element. We vibration isolated and thermally stabilized the cavity to +/- 0.1 degree Celsius. This slows the cavity mode drift to a rate that is easily compensated with a feedback loop. Sensing the prelase signal, we adjust the cavity length to keep one mode at the peak of the phase shift grating fringe.

Using a dual high speed phase modulator chip, we have generated 3 Angstroms bandwidth at 12GHz modulation frequency, for smoothing by spectral dispersion (SSD). Two 2-watt solid state amplifiers drive the electrooptic modulator, which is similar to that used for the 3GHz SBS suppression modulation. When operating either of these phase modulators we see tens of percent peak-to-peak amplitude modulation on the optical pulse. Based on separate measurements and calculation, we attribute this modulation to spectral filtering by the combination of birefringent polarization-maintaining (PM) fiber and polarizing elements throughout the MOR system. To mitigate this problem, we are replacing the PM fiber with polarizing fiber, which guides only one polarization.

We have investigated the characteristics of a chain of fiber amplifiers which simulate the 1-to-48 splitter and amplifier tree in the NIF design. These amplifiers use two Yb-doped fibers with different core sizes, to achieve the required gain and saturation energy. Between stages, isolators and narrow band filters prevent oscillation and propagation of ASE. The splitters are polished PM directional couplers, which have a high damage threshold. At several Joules/cm^2, the peak fluence is highest at this point in the system.

Tests of a prototype arbitrary electrical waveform generator show that we can create highly stable pulses with 250ps resolution up to 24ns long under computer control. The output waveform is recorded on a sampling oscilloscope and fed back to a controller to make the waveform converge to the desired temporal shape. To create high contrast shaped pulses, we automatically insert an attenuator in the diagnostic path to change measurement ranges. Otherwise, the oscilloscope digitizing error limits dynamic range.

We are testing all of these components together to investigate integrated system issues. In addition, the development MOR sends pulses to the development preamplifier, to simulate the whole NIF front end system.

USING A CHIRP-PULSE-AMPLIFICATION TECHNIQUE FOR FLEXIBLE SHAPING OF BROADBAND LASER PULSES

A.B.Van'kov, A.A.Kozlov, V.E.Yashin
Institute for Laser Physics, 12 Birzhevaya line, St.Petersburg, 199034 Russia,
Phone: (812)218-1093, Fax: (812)218-5891, E-mail: yashin@ilph.spb.su

Precise spectral and temporal pulse shape control is necessary for the fusion laser facilities. A number of approaches were suggested for generation of broadband pulses with complex time shape[1]. In this paper, another approach based on chirped-pulse-amplification (CPA) technique is discussed.

Laser system based on this approach usually consists of short pulse master oscillator (MO), diffraction grating pulse stretcher (St) and regenerative amplifier (RA). Ti:Al_2O_3 or Nd:glass master oscillators generate broad band 0.1-1 ps pulses. Those pulse lengths define in principle the resolution of pulse shaping system and time of intensity averaging on the target. To produce nanosecond pulses with duration 0.5-5 ns a pulse stretchers on diffraction gratings are used. To modify the pulse shape of this pulse a pulse stacker based on RA can be used. The length of MO cavity is closed to RA one so that the pulse train from MO form a single modulated pulse with shape defined by relative amplitudes of initial pulses. Those amplitudes can be flexibly varied using electro optical modulators based on Pockels cells or deflectors. A low intensity pedestal usually needed for target compression can be produced by Q-switching of RA before arriving the first pulse from MO.

A pair of diffraction gratings can recompress the pulse after RA. By this means a shaped train of subpicosecond pulses can be provided with period determined by length's differences of MO and RA cavities. Changing of cavity's length of RA a period of this train can be varied within large limits (from picoseconds up to nanoseconds).

In conclusion, a method based on CPA amplification technique is suggested to control shape intensity with subpicosecond resolution. Those laser pulses can be used for fusion, X-ray generation and another applications.

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The Spatial Filters Used in Multi-pass Amplification System

Y. Zhao , Q. Zhu , X. Zhang and F. Jing

Laboratory for Laser Fusion
Southwest Institute of Nuclear Physics and Chemistry
P.O.Box 525-80,Chengdu 610003,China
Fax:86-816-2271598)

The spatial filters are used in Technical Integration Line (TIL) , which has a multi-pass amplifier, not only to suppress parasitic high spatial frequency modes but also to provide places for inserting a light isolator and injecting the seed beam, and to relay image while the beam passes through the amplifiers several times. To fulfill these functions, the parameters of spatial filters have been optimized by calculations and analyses with the consideration of avoiding the plasma blow-off effect and components damage by ghost beam focus. The pencil beams are calculated by tracing the beamlines from both directions. The beam reverser has been carefully designed, in which, a new kind of electro-optical switch is used to decrease the B-integral increasing and to promote the intensity fluence. In addition, the method to align the whole system has been developed.

RAPID GROWTH OF LARGE KDP and DKDP CRYSTALS: THE CONNECTION BETWEEN GROWTH CONDITIONS, SIZE AND CRYSTAL QUALITY

N.Zaitseva, J. Atherton, W. Bell, .L.Carman, S. Couture, M.Dehaven, J. De Yoreo, L. James, M. Martin, H.Robey, R. Rozsa, R. Spears, R.Torres, R. Vital and M.Yan.

Lawrence Livermore National Laboratory (LLNL)
P.O.Box 808, Livermore, CA 94550,
zaitseva1@llnl.gov

Large KDP crystals with sizes up to 450 mm had been grown previously in crystallizers with a volume of 1000 L at growth rates of up to 10-20 mm/day. First measurements of optical quality (depolarization loss, light absorption, wave front distortion and damage threshold) [1] showed that, in general, large rapidly grown crystals can be as good as small crystals grown both by the traditional or rapid techniques [2].

In this paper we report the recent results on rapid growth of KDP and DKDP (90% deuterated) crystals of up to 57x57 cm^2 in crossection and up to 55 cm in height. Crystals were grown by the temperature reduction method starting from a saturation point 65-75°C to room temperature and lower, down to 8-10°C. This progress was made possible due to the scientific and technical research performed to understand the problems connected with scaling the growth process. The effect of different factors, such as impurities, stress, growth rate and regeneration conditions, have been investigated for the case of large crystals. The design of the 1000 L crystallizer, as well as the design of the platform-crystal holder have been modified to provide the conditions required for the growth of 250 kg crystals. All growth tanks were equiped with constant filtration systems, specially designed for operating at the high supersaturations needed for fast growth. It has been proven that the constant filtration was one of the important conditions required for obtaining crystals of high damage threshold and optical uniformity.

37x37 cm^2 and 41x41 cm^2 single crystal plates have been cut from the grown crystals for optical measurements and use on Beamlet, the NIF prototype, currently operating at LLNL.

*Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-ENG-48.

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The LULI 100-TW Ti:sapphire/Nd:glass laser: a first step towards a high performance petawatt facility

J.P. Zou, P. Audebert, D. Descamps, S. Baton, D. Pesme, A.-M. Sautivet, H. Timsit and A. Migus

Laboratoire pour Utilisation des Lasers Intenses, CNRS, Ecole Polytechnique, 91128, Palaiseau, France

Abstract

A sub-picosecond laser plasma facility based on Chirped Pulse Amplification (CPA) has been developed at LULI. This system which uses broad bandwidth Ti:sapphire technology and mixed Nd:glass amplifiers is producing pulses of 100 TW peak power (typically 30 J-300 fs) on target. This paper will describe the present set-up characteristics and its main path of progress towards a high performance petawatt facility.

The existing laser system is based on well-known technologies:

1.) The front-end starts with a commercial mode-locked Ti:sapphire oscillator delivering 100 fs pulses at 1057 nm, a four-pass double-grating stretcher expands the pulses to 1.3 ns duration, and a home-made TEM_{00} Ti:sapphire regenerative cavity with an effective gain of up to 10^7 delivers 5mJ pulses of 8 nm bandwidth at a 10Hz repetition rate.

2.) The Nd-glass power chain is composed of four amplification stages with successive diameters of 16, 25, 45 and 108 mm; each of the first three stages consists of a phosphate LHG8 and a silicate LSG91H rod amplifier; the last amplification stage is a 108 mm LHG8 disc amplifier used in a double-pass configuration. This line is able to generate a 150J chirped output pulse with a flat top profile without noticeable spectral narrowing.

3.) A home-designed pulse compressor in vacuum uses a double-pass scheme with two gratings of 420mm width. It is connected to a vacuum target chamber where the pulses are focused with an off-axis parabola onto a 1.5-times diffraction limited pulse.

The limited size and damage threshold of the compressor gratings set an upper limit for the energy sent on the gratings, of the order of 40 J which, taking into account the 75% efficiency of the optics, corresponds to 30J compressed on target. Therefore, the chirped pulse is previously split into two pulses, one going to the compressor, the other one, typically 60 J or above, being used for plasma creation. The compressed pulse has also been frequency doubled with a high efficiency and its high contrast has been characterized in experiments on targets. An independent 15 mm diameter, 100 mJ, synchronized probe beam is also available, with a pulse duration adjustable from 300 fs to 100 ps and a possibility of being frequency doubled.

We will describe the program of improvements now being implemented for an upgrade of this 100TW system: a) use of an achromatic stretcher in order to fully use the available bandwidth and compress the pulses to 200fs duration, b) optical adaptive correction based on liquid crystal technology which should allow to increase the Strehl ratio to near a unit value, c) larger and higher damage threshold gratings and developed in partnership with European companies, and, d) diode pumping of the initial amplifiers in order to inject at a few hertz repetition a few joules of chirped pulses rate into the large disk amplifiers.

Submitted to 3rd ICF, Monterey, June 1998

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MP

FOCUSING OPTICS DESIGN FOR THE UK 100TW CLASS LASER

J.E. Andrew, T.H. Bett, P.M.R. Jinks, K.W. Parker & R.M. Stevenson

AWE plc, Aldermaston, Reading, Berkshire, United Kingdom, RG7 4PR

The proposed UK 100TW class laser will use the same multipass architecture, beam clustering and beam size as that employed in the National Ignition Facility (NIF) but with 32 beams. The individual beamlets will be used in a configuration of four rings of eight beams to allow optimum irradiation of indirect drive targets. The application of the laser system in this manner will imply the use of comparatively smaller targets than that used on NIF.

This feature means that it is essential to reduce the focal spot size of a beamlet by using a shorter focal length lens than employed on NIF yet with as small an optical path as possible in order to limit beam filamentation caused by non linear effects in the lens material.

The final optics system design is based on the NIF configuration and employs a fused silica singlet of plano - aspheric shape. A reflection from the flat input surface of the lens is used to diagnose the third harmonic beam profile in the near field. The complete final optics configuration is based upon a target chamber vacuum window, Type I second harmonic generation crystal, Type II third harmonic generation crystal, focusing lens, phase plate and debris shield.

This paper addresses beam propagation beyond focus, through the target entrance aperture and onto the target wall. Techniques used to verify the suitability of the final optics assembly design for use with possible target designs are described.

In addition analysis of ghost reflections from the components in the assembly are presented for both normal and non normal incidence configurations. Initially families of problem ghost rays are identified by paraxial ray tracing. Once identified more detailed beam analysis is performed with a variety of techniques to evaluate the risk of damage by such reflections as well as leading to specifications for the maximum reflectivity of the contributing surfaces. Alignment tolerances for the optical assembly have also been investigated.

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MODELING OF FREQUENCY DOUBLING AND TRIPLING WITH CONVERTER CRYSTAL REFRACTIVE INDEX SPATIAL NON-UNIFORMITIES

J. M. Auerbach, C. E. Barker[1], S. A. Couture, D. Eimerl, J. J. De Yoreo, R. L. Hibbard, L. W. Liou, M. A. Norton, S. A. Perfect, L. A. Hackel

University of California
Lawrence Livermore National Laboratory
PO Box 808, Livermore, CA 94551

[1] Current address:
Silicon Valley Communications Inc.
931 Benicia Ave., Sunnyvale, CA 94086

The NIF Frequency Converter utilizes large 40 cm aperture crystals of KDP and KD*P. The crystal growth, finishing, and mounting processes for these crystals results in a non-flat surface and in an internal stress distribution. This leads to spatially varying indices of refraction and hence spatially varying departures from the phase-matching condition. In addition deformation and induced stress is also caused by gravity in the case of crystals not mounted in a vertical plane.

Accurate prediction of frequency conversion in NIF requires that the spatial variations of the departure from the phase-matching condition be included in the converter model. We have done this by using a spatial varying distribution of the phase mismatch factor Δk. The distributions of this factor are defined either from stress-optic calculations or measured interferometry data.

Calculated spatial distributions of output harmonic light agree well with near-field distributions of 2ω and 3ω light measured on the BEAMLET laser. We have accurately predicted the near-field intensity modulation patterns due to mounting stresses and crystal growth non-uniformities.

* Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

Amplitude Modulation of kilowatt laser pulses with LNO Pockels cells Experiments and results on Phebus facility

BAR E., BAILLY-SALINS R., BOUBAL F.(Stagiaire), BOYER N. (Stagiaire)

CEA/LV - Département des Lasers de Puissance
F- 94195 VILLENEUVE-ST-GEORGES Cedex
Fax : (33) 1 43 86 74 01

The monomode, 1053nm, Nd :YLF Master Oscillator (MO) of Phebus facility delivers 100µJ in 1 to 4ns pulse which is temporally shaped and preamplified before the power line. To compensate the saturation of the power amplifiers of the line, the time profile is shaped from a 100ns pulse by means of KDP Pockels cells driven by microwave lines [1] loaded under 8kV and switched by silicium photoconductive devices. We have experimented another way [2] of making amplitude modulation by using LNO massive crystals [3] according to the design of the Front End of LMJ facility in case of smoothing by optical fiber.
These electro-optical crystals are ruled by transverse Pockels effect. The survey is limited to crystals whose z-axis is orthogonal to optical windows and whose dimensions are 2x2x15mm. The modulation function (T) versus the high voltage (V) determining the electrical field can be written as $T = \sin^2\left(\frac{\pi}{2}\frac{V}{V_\pi}\right)$ where Vπ, the half-wave voltage is worth 2700 V.
The MO pulse required for Phebus facility is shown in figure 2. The rise and fall times are 250ps and the signal to noise ratio is greater than 50dB. The energy is about 1µJ behind th modulator. The way of building 4ns shapes has been demonstrated by sending 16 high voltage exponential pulses passively delayed with different lengths cables for the rising part. The sample step is 250ps (5cm). The peak of each sample can vary with programmable attenuation from 0 to 31dB (step of 1dB) and 1GHz of bandwidth. So each way out can deliver 400V and the amount must be 2500V. We use for that a « 6419NFP/BARTH » divider/combiner and « AP10-31/NUCLETUDES » attenuators. The falling part is made by two 1250V synchronized negative pulses. These voltages are generated by a « HMP2/KENTECH » pulsed power supply. It delivers 4000V and -4000V in independent 50Ω loads with a 130ps rise time and 15ns approximately exponential width. The jitter relative to external trigger is less than 30ps. The interconnexions between the global electrical supply and the optical device are realized by coaxial connectors mounted on electrodes pasted to the crystal.
This configuration has been simulated and tested by power shots at Limeil. The first results show a very good agreement with the expected shape despite rise time is rather 500ps and the signal to noise ratio about 35dB (cf. fig. 2).
We place a second crystal with a smaller equivalent capacity behind the first one to create an optical gate with a shorter rise time to increase the dynamic of the device. We expect a 300ps rise time and a theoretical 50dB signal to noise ratio. After amplification and first simulations of frequency conversion, we observe a 2.7kJ - 3.8ns square laser pulse at 353nm with a flat top.
With the second crystal, the rise and fall time must be respectively reduced to 280ps and 350ps at the end of the power line because of frequency conversion efficiency. These last results still have to be verified with others shots.

As a conclusion, we have exposed an original way of modulating high intensity laser pulse with a bulk LNO modulator and 4000V voltage supply. This purpose has been successfully tested on Phebus facility and the temporal shapes have been designed and validated according to the profiles expected on targets with less than 300ps of rise time and 50dB signal to noise ratio.

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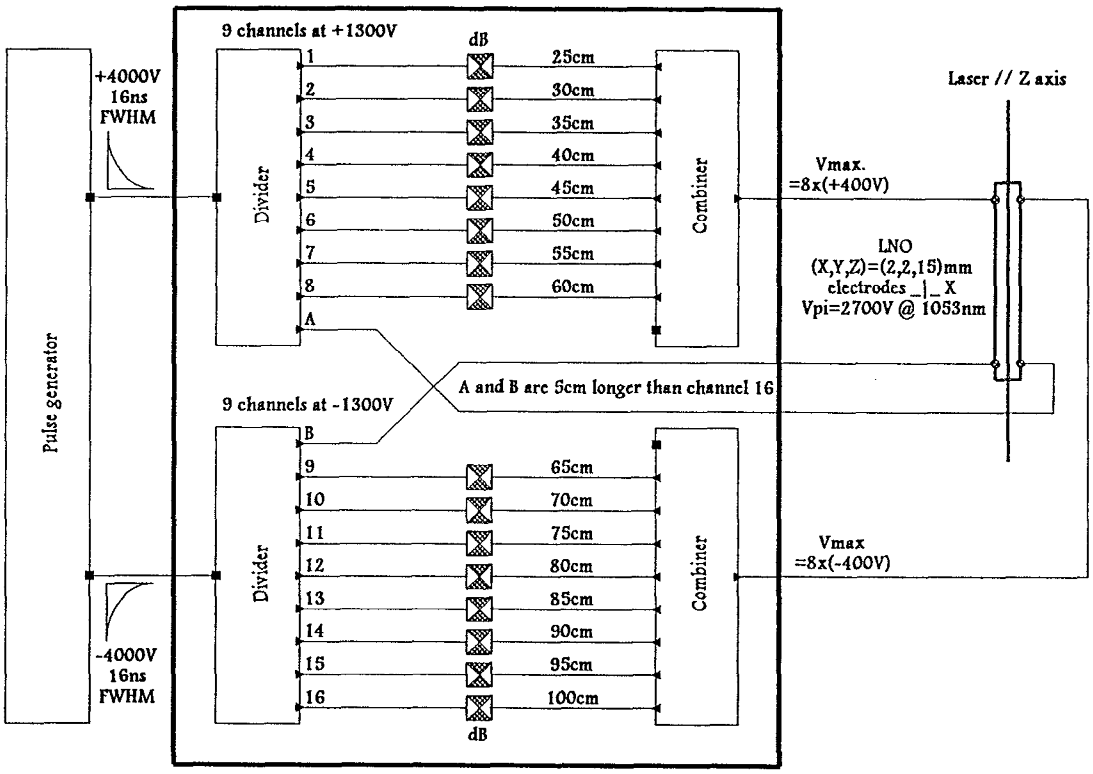

Fig. 1 : Experimental design

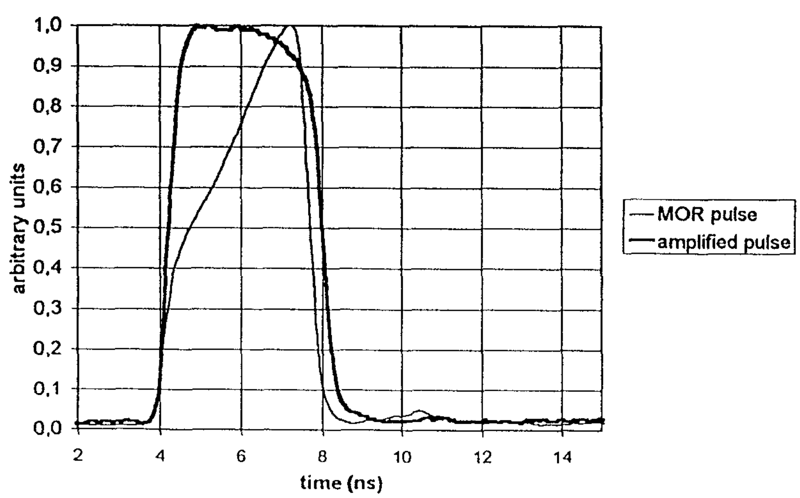

Fig. 2 : Test shot in the power line of Phebus (1ω)

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W1B-3

DIFFRACTIVE BEAM SAMPLERS FOR LARGE APERTURE BEAM DIAGNOSTICS

T H Bett, A R Barnes, I C Smith

AWE plc, Aldermaston, Reading, Berks, UK, RG 7 4 PR

Diffractive beam samplers have been employed for some time on the HELEN laser at AWE. The phase gratings combine two functions viz. sampling and focusing in one element. The weak phase modulation generates low power diagnostic beams from which energy measurements have been made. The diffraction efficiency is fixed on fabrication by the depth of the grating. Focusing power has been added to the large aperture gratings to reduce the beam size to a convenient size for a detector.

These gratings are fabricated in fused silica substrates by ion beam milling through a photo-resist layer with the desired grating pattern recorded holographically.

The paper reports on further beam characterisation measurements through recording far field and near field intensity distributions of beams up to 200mm diameter.

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W1B-2

BEAM-SHAPING DIFFRACTIVE OPTICAL ELEMENTS FOR HIGH-POWER SOLID-STATE LASER SYSTEMS

Ian M. Barton, Paul Blair, Andrew J. Waddie, Karsten Ballüeder
and Mohammad R. Taghizadeh
Department of Physics, Heriot-Watt University, Edinburgh, EH14 4AS, UK.

Hazel McKinnes and Tom H. Bett
AWE UK, Aldermaston, Reading, UK.

Tel: +(44) 131 451 3067 Fax: +(44) 131 451 3136
Email: phymt@phyfs1.phy.hw.ac.uk

We apply diffractive optical elements (DOEs) to a number of laser beam-shaping tasks. These tasks include customisation of the modes of a laser resonator, lensless beam propagation and a free-space Gaussian to flattop beam conversion. DOEs are inherently suited for operation with high-power laser systems due to their excellent functionality and efficiency, and the high damage threshold of applicable substrates, e.g. fused silica for UV to near-IR wavelengths.

The potential for DOEs as intra-cavity mode-selection devices has been demonstrated over the last few years. They have been mainly applied in solid-state laser systems, e.g., Nd:YAG, to generate flattop-shaped fundamental modes. These customised resonators give advantages over standard resonators both in terms of better power extraction from the amplifiers and more useful output beams.

Usually MSEs operate as specific phase conjugation devices to select the desired mode profile. A signal MSE that replaces one mirror in a Fabry-Pérot cavity can generate an arbitrary real mode profile at the opposite mirror. Recently we have employed numerical optimisation algorithms to design mode selecting elements (MSEs), allowing the generation of better quality flattop modes.

A number of MSEs were designed for operation in a ND::YAG resonator. The MSEs were fabricated as transmitting 16-level elements in fused silica using photolithography with reactive-ion etching. The length of cavity was 1m, with the generated mode being a high-order circular super-Gaussian of -2mm diameter. The element was designed to be positioned at the input mirror, resulting in a flattop being formed at the output. The output profile of the custom resonator, as measured by a CCD camera is shown in figure 1.

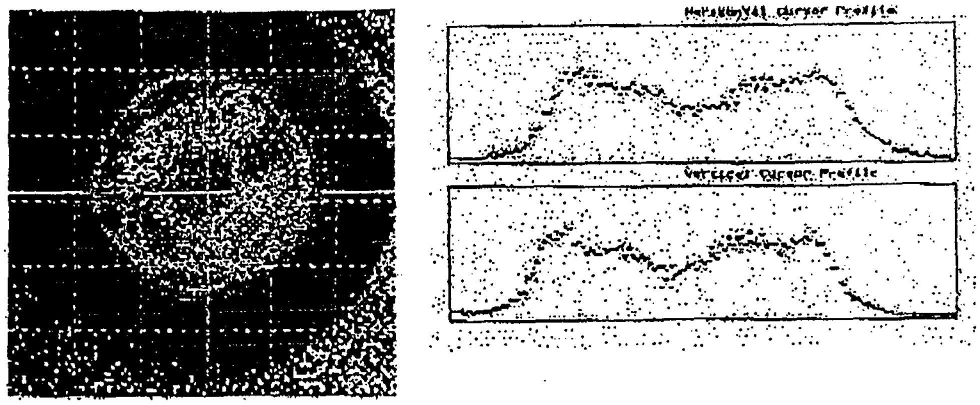

Figure 1. Experimental output of a custom laser resonator.

The same element was also applied in a single pass configuration. In this case the customised cavity was seeded with a -2mm diameter flattop. The resulting beam profile was ejected from the cavity after a single pass and the beam profile examined. As expected, a flattop shape was recovered. This is equivalent to lensless free-space propagation.

The conversion of the fundamental Gaussian TEM_{00} mode to other intensity profiles, particularly the circularly symmetric flat top distribution, is another application to which the DOE is well suited. Applying the stationary phase principle to the Fresnel integrals, formed from the prescription of the TEM_{00} mode and the required intensity profile, provides the continuous phase profile for the DOE necessary to perform the transformation. Iterative optimisation techniques are applied to remove the noise introduced after quantisation; a step required by our fabrication techniques.

The DOE is designed to operate in the near-IR wavelengths and to convert a TEM_{00} beam of diameter of ~20 mm to a circular flattop of diameter ~15 mm after a distance of 2m. The efficiency with which this can be performed is ~90% for 16 quantisation levels. To allow for image relaying downstream of the DOE, a second element is placed in the image plane to flatten the phase of the wavefront.

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TU3B-5

DESIGN PROGRESS FOR NIF LASER ALIGNMENT AND BEAM DIAGNOSTICS

E.S. Bliss, S. Boege, R. Boyd, D.T. Davis, R. Demaret, M. Feldman
A. Gates, F.R. Holdener, C. Knopp, R. Kyker, C. Lauman, T. McCarville
J. Miller, V. Miller-Kamm, W. Rivera, T. Salmon, J.R. Severyn
S. Sheem, S. Thomas, C. Thompson, M. Yoeman, R. Zacharias
Lawrence Livermore National Laboratory
P.O. Box 808, L-495, Livermore, CA 94551
(925) 422-5483, bliss1@llnl.gov

Cliff Chocol, John Hollis, D. Whitaker
SAIC
San Diego, CA

J. Brucker, L. Bronisz
Los Alamos National Laboratory
Los Alamos, NM

T. Sheridan
Allied Signal Corporation
Kansas City, MO

Detailed design of alignment and diagnostic systems for the National Ignition Facility (NIF) laser is in its last year. Specifications are now more detailed, additional analyses have been completed, Pro-E models have been developed, and prototypes of specific items have been built. In this paper we update top level concepts, illustrate specific areas of progress, and show design implementations as represented by prototype hardware.

The alignment light source network has been fully defined. It utilizes an optimized number of lasers combined with fiber optic distribution to provide the chain alignment beams, system centering references, final spatial filter pinhole references, target alignment beams, and wavefront reference beams.

The input and output sensors are being prototyped. They are located respectively in the front end just before beam injection into the full aperture chain and at the transport spatial filter, where the full energy infrared beam leaves the laser. The modularity of the input sensor is improved, and each output sensor mechanical package now incorporates instrumentation for four beams.

Additional prototype hardware has been tested for function, and lifetime tests are underway. We report on spatial filter tower vibration characteristics, pinhole insertion mechanism accuracy and lifetime, and data processing electronics tests.

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TH3A-3

PRELIMINARY DESIGN FOR THE CAVITY END DEFORMABLE MIRROR OF THE LASER MÉGAJOULE

Xavier BOZEC[1], Renaud MERCIER YTHIER[1], Jean Louis CAREL[1], Pierre COUSTAL[1], Jean Luc MICHELIN[2], Pierre JOLY[3]

[1] *REOSC, Avenue de la Tour Maury, 91280 SAINT PIERRE DU PERRAY, FRANCE*
Tel: 33.1.69.89.76.89 Fax: 33.1.69.89.76.20
[2] *SFIM INDUSTRIES, 13 Avenue Ramolfo Garnier, 91344 MASSY Cedex, FRANCE*
Tel: 33.1.69.19.66.00 Fax: 33.1.69.19.69.16
[3] *CEA, Centre d'études de Limeil, 94195 VILLENEUVE SAINT GEORGES, FRANCE*
Tel: 33.1.45.95.62.64 Fax: 33.1.43.86.74.06

In the framework of the Laser MégaJoule program, Groupe SFIM including REOSC and SFIM Industries have proposed a preliminary design of the cavity end deformable mirror to correct wavefront aberrations of the laser beam.

The CEA requirements analysis shows that the deformable mirror shall be designed with respect to the four following figures of merit: performances, reliability, maintainability and lowest cost.

The main technical requirements for the mirror deformable are:

- high accuracy mirror surface deformation control (local slope errors < 1 µrad for deformation amplitudes of 10 µm and < 0.5 µrad for mirror zero deformation)
- two axis tilt mirror mechanism (accuracy of 0.6 µrad with a 1300 µrad stroke)
- mirror roughness of 2.5 nm RMS for periodic defects in the range [1mm 10mm]
- a system bandwith of 1 Hz and a linearity less than 0.1 µrad for small deformation angles

The design proposed to fulfill these requirements is based on a force control strategy. Forces are generated by specific designed electromechanical actuators and transmitted to a Zerodur 400 x 400 mm mirror through an annular soft pad. This pad is optimized to filter high frequency ripple generated by the spatial sampling of the efforts at the back of the mirror. In order to decrease the needed number of actuators, and thus the cost of the deformable mirror, a mathematical method was specifically developed and used to find the best actuator patter fitted to the wavefront aberrations to be corrected.

The surface quality of the zerodur mirror is achieved by using an annular polishing method, removing the high spatial frequency defects and tolerating a few low frequency defects like focus and astigmatism that can be compensated by actuators.

A specific mechanism based on flexible articulations and stepper motor is implemented to perform the two axis tilt motion. The electronic device is limited to a single board plugged at the back of the actuators. Due to the low power consumption of the system, only one power supply is required for eight deformable mirrors (one LMJ laser line).

Analysis, calculations, finite elements models, preliminary tests and validations on breadboard models have shown that the proposed-design is compliant with the functional and operational requirements. A design description and the main justifications, as the guidelines of mirror integration and the experimental devices planned to control it are given in this paper.

Due to the simplicity of the concept and the use of validate and mastered technologies at SFIM Industries and REOSC, the design presents a good reliability. Furthermore, a complete and very easy to work maintainability is favored by this deformable mirror definition. Each parts of the system (electronics, actuators, tilt mechanism) is easily removable and replaceable on the laser line without carrying out an heavy procedure and complex tools.

This work was mainly supported by Groupe SFIM Research and Development program and partially funded by a CEA contract.

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TH3B-2

STITCHING INTERFEROMETER FOR LARGE OPTICS: RECENT DEVELOPMENTS OF A SYSTEM

Michael Bray
Cilas, Orléans, France

Cilas, 8 Av. Buffon, Z.I. de la Source, 45063 Orléans Cedex
Tel: (+33) 2 38 64 15 15 Fax: (+33) 2 38 76 02 49
E-mail: mbray@cilas.com

We have developed a stitching interferometer for use with large optics, such as those used in Laser MégaJoule and NIF (sizes up to 800 by 400 millimetres).

The idea behind this technique is that, to keep resolution at its highest value, a "small" aperture (100 millimetres) phase-shifting interferometer must be used. But this means that measurement of the complete component has to be performed by stitching the individuals sub-apertures together.

We have overcome most of the obstacles involved in stitching interferometry, and have been using one such system at our optical and laser production facility in Orléans for some years. We have previously reported transmission measurements performed on Phebus laser slab (Paris'96).

We present here measurements performed on Laser MégaJoule transport mirrors measured in a horizontal position (to check on gravity's effect), and on glass inhomogeneity *without* oil plates. This latter requires multiples takes on each sub-aperture, and additional computing, but the whole process has been automated.

In addition, we contribute to the pretty picture department by showing graphical results perhaps never previously seen.

This work was performed under contract from CEA-LV, as part of the Laser MégaJoule development.

Solid State Lasers for Application (SSLA) to Inertial Confinement Fusion (ICF)

Third Annual International Conference

June 7 - 12, 1998
Monterey, California, USA.

Title : **Localised wavefront deformations : propagation in non-linear media (II) (a simple but accurate computational method)**

Authors : **Michael Bray, Cilas, Orléans, France**
Geneviève Chabassier, CEA-LV, Limeil-Brévannes, France

Mailing : **CEA-LV/DLP/CSL/LTO**
Limeil-Valenton
94195 Villeneuve Saint Georges Cedex

Tel : (+33) 1 45 95 61 38
Fax : (+33) 1 43 86 74 07

Preferred : **Oral**

Abstract :

The propagation of waves in non-linear media (such as the final amplifier sections in Laser MégaJoule) is perturbed by the fact that the index of refraction of such media is modified by the intensity of the wave which, in turn, modifies the shape of the wave which, in turn, modifies the intensity of the wave... and so on.

A localised small concavity in the wavefront due, typically, to un-perfect components, also perturbs the wavefront by creating a localised intensity peak further down the line.

The computation of such modulation is relatively easy in vacuum, by simple wave summation according to Fresnel, but rather less so in non-linear media. This is because the above-mentioned index variations modify the actual optical path of the rays as compared to vacuum.

For shallow defects, a simple but effective method is to proceed via the Fourier transform of the defect shape. Individual spatial modes ("sinusoids") propagate with accurately-known amplitude variation. Modes are summed up after individual propagation, leading to accurate results.

The amplification of such modes can be *very* great, leading to many-fold amplification of localised intensity peaks and, therefore, to potential damage to optical components.

We explain the method, with little mathematics, and compare numerical results with "real" simulations performed on *MIRÓ* (CEA's laser propagation code).

Additionally, as we show, insight into the behaviour of defect amplification is gained, and accurate predictions can be made with little or no computational effort.

This paper follows part I, given at Glasgow'96 : "Using First Principles in the specifying of optics for large high power lasers (I). Application to the MégaJoule Laser (LMJ)".

Constraints on Target Chamber First Wall and Target Designs That Will Enable NIF Debris Shields To Survive

Alan K. Burnham[a], Michel Gerassimenko[a], John Scott[b], Jeff Latkowski[a], Pam Whitman[a], Francois Genin[a], Wilthea Hibbard[a], Per Peterson[b], Bob Tokheim[c], Don Curran[c]

[a]Lawrence Livermore National Laboratory, Livermore, CA 94551
[b]University of California, Berkeley, CA 94720
[c]SRI International, Menlo Park, CA 94025

Abstract

The target chamber interior materials and target designs themselves have to be compatible with survival of the debris shields. Current plans are to retrieve, clean, and recoat the debris shields weekly, and refinish them after 6 months. This means that the exposure to metal vapors, dust, and shrapnel must not exceed a critical threshold during one week. Recent experiments and modeling have better quantified the threat to optics, including the direct threat of shrapnel and x-rays from targets as well as the indirect threat due to remobilization of target and beam dump debris from the first wall by x-rays. Initial indication are that the contamination rate of the debris shields can not exceed about 1 nm per shot total material. This implies that the target mass must be limited to no more than 1 gram and the ablated mass from all other components must not exceed 2 grams. In addition, the targets themselves must either completely vaporize or send any minor amounts of shrapnel towards the chamber waist to prevent excessive cratering of the debris shields.

The constraints on the first-wall ablation require that it be louvered to provide passive collection of remobilized contamination, because the expected target debris will remobilize at a rate fast enough to require cleaning every three weeks, about three times more frequent than possible with planned robotics. Furthermore, a comparison of ablatants from B_4C and stainless-steel louvers suggests that remobilization of target debris by x rays will be greater than of the base material in both cases, thereby reducing the performance advantage of clean B_4C over much-cheaper stainless steel. Neutronics calculations indicate that activation of thin Ni-free stainless steel is not a significant source of maintenance personnel radiation dose. Consequently, the most attractive first wall design consists of stainless-steel louvers. Evaluation of various unconverted light beam dump designs indicates that stainless steel louvers generate no more debris than other materials, so one single design can serve as both first wall and beam dumps, eliminating beam steering restrictions caused by size and location of the beam dumps. One reservation is that the allowable contamination rate of the debris shield is not yet completely understood, and it is likely that either a thin polymeric pre-shield or a rapid post-shot gas purge of the final optics assembly will be required to prevent low-energy contamination from reaching the debris shield.

*Work performed under the auspices of the U. S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-ENG-48.

Abstract for the 1998 SSLA-ICF Third Annual Conference

Key words: NIF Target Chamber, x-ray ablation, shrapnel generation, laser damage

The Z-Backlighter, a Laser X-ray Diagnostic for High Energy Density Physics in Matter (*)

J. A. Caird, A. T. Anderson, G. L. Hermes, O. L. Landen, J. E. Murray, J. M. Narduzzi, M. A. Norton, C. D. Orth, L. G. Seppala, S. C. Sommer, J. M. Spann, C. J. Stolz, and G. L. Tietbohl

University of California, Lawrence Livermore National Laboratory (LLNL)
P. O. Box 808, L-479, Livermore, CA 94550

J. L. Porter, R. G. Adams, H. C. Ives, and W. W. Simpson

Sandia National Laboratories
P. O. Box 5800 Mail Stop 1194, Albuquerque, NM 87185-1194

[Abstract submitted to the Third Annual International Conference on Solid State Lasers for Application (SSLA) to Inertial Confinement Fusion (ICF), June 7-12, 1998, Monterey, CA]

The Z-Accelerator facility at Sandia National Laboratory (SNL) in Albuquerque, New Mexico, performs critical experiments on the physics of matter at high energy density as part of the Department of Energy's nuclear weapons Stockpile Stewardship Program. In order to augment and enhance the value of experiments performed at this facility, a new x-ray backlighting diagnostic system (the Z-Backlighter) has been designed. New information will be obtained by recording images and/or spectra of x-ray radiation transmitted through target materials as they evolve during Z-Accelerator driven experiments (or "shots"). The methodology involves implementation of the general sciences known as x-ray radiography and/or x-ray spectroscopy. This paper reports on the design of the laser system, and on experiments that have been done to determine characteristics of x-ray emission relevant to the Z-Backlighter system performance.

X-ray backlighter experiments have been performed at ICF facilities in many countries. At LLNL experience has been obtained using the Nova laser system since about 1986. An intense source of x-rays is produced by focusing one of its beams on a backlighter target nearby, while the other beams are used to create the high energy density conditions to be studied in the experiment. The Z-Accelerator produces similar conditions in targets driven by over 10 Mega-Joules of electrical energy deposited in a magnetic z-pinch configuration. The Z-Backlighter will provide x-ray diagnostic capabilities comparable to one beam of Nova at the Z-Accelerator.

The architecture of the Z-Backlighter is very similar to the Beamlet laser[1] which has operated at LLNL since 1995 as a scientific prototype for the National Ignition Facility. We take advantage of several technological advances that were not available when Nova was built. This allows for Z-Backlighter performance comparable to a single Nova beam with greatly reduced complexity and cost. The development of a full aperture plasma-electrode Pockels cell (PEPC)[2,3] allows the beam to traverse the main cavity amplifier four times to provide effective use of the gain as well as efficient use of energy stored in the amplifiers. This feature allows the system to fit into a much smaller space than comparable Nova technology, and enables deployment within space available at the Z-Accelerator facility. Efficient frequency conversion (up to 80%) from the fundamental infra-red frequency (1ω) to the green (2ω) is

*Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-ENG-48. Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed-Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000.

accomplished in single, full aperture KDP and KD*P crystals (compared to the 9-aperture segmented crystal array on Nova). In addition, high beam quality is achieved through active wavefront correction by a deformable mirror (DM) adaptive optic. This allows generation of focal spots as small as 3 times the diffraction limit at 1ω.[4,5] The small focal spot size is a key requirement enabling high resolution x-ray images to be generated by the Z-Backlighter. Key operational characteristics of the Z-Backlighter laser system include:

• Laser output energy (2ω, 2 ns)	2.0 kJ
• Focal spot diameter (75% energy)	50 μm
• Irradiance on target	3×10^{16} W/cm^2
• Shot rate	2/day
• Pulse duration [not to preclude ps operation]	0.2 ns to 2 ns
• Temporal pulse format capability	picket fence [up to 4 in 20 ns]

Most of the hardware in the Z-Backlighter laser system will come from recycled parts of the Beamlet and Nova Lasers which are planned to be decommissioned at LLNL in 1998, and 1999 respectively. The estimated value of components being recycled for this application is $5M. The schedule for the project involves site preparation beginning in 1998. The Beamlet front end will be reactivated at Sandia in the beginning of 1999. Nova 31.5-cm amplifiers, capacitor bank, and spatial filter equipment will be added later in 1999, with full system activation expected at Sandia in 2000.

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TH2B-4

PROGRESS ON DEVELOPMENT OF CONTINUOUS GLASS MELTING FOR PRODUCTION OF LASER GLASS NEEDED FOR THE NIF AND LMJ*

John H. Campbell, Mark J. McLean, Ruth Hawley-Fedder, Tayyab I. Suratwala
University of California
Lawrence Livermore National Laboratory
P.O. Box 808, L-500
Livermore, CA 94551-9900
(925) 422-6497

Gaëlle Ficini-Dorn
CEA-Centre d'Etudes de Limeil-Valenton
94195 Villeneuve-Saint-Georges - Cédex, France

The NIF and LMJ require about 3,000 and 4,000 neodymium-doped laser glass slabs, respectively. Each finished glass slab is 81 X 46 X 4.1 cm^3 in size and contains neodymium at a doping density of 4.2 X 10^{20} ions/cm^3. A production rate of finished slabs of about 1,000/year is needed to meet the current NIF construction schedule. The only glass melting method capable of meeting this slab production rate is continuous melting technology. Recent progress at Schott Glass Technologies (Duryea, PA) and Hoya Optics (Fremont, CA) demonstrating continuous laser glass melting will be discussed. Both vendors have carried out test melting campaigns of their proprietary melting technology. The test runs typically lasted more than a month yielding many tons of glass product. Most of the details of these runs and the performance of the melters are proprietary and can only be discussed in general terms. Nevertheless our confidence in the development results is sufficient that we are progressing with final facilitization. The buildings required to house the laser glass production facilities have been completed at both vendors and modifications to the demonstration melting hardware are underway. In addition, both vendors are also facilitizing melters to produce the required cladding glass. Twenty tons of high purity neodymium salts are presently being produced by the rare earth vendor (Rhône-Poulenc, La Rochelle, France) and are undergoing round-robin chemical analysis and acceptance testing. This neodymium will be used in the pilot run. Approximately one metric ton of high purity platinum is on loan to Lawrence Livermore National Laboratory (LLNL) from the U.S. Government for use as an inert refractory metal liner in the continuous melting systems. Negotiation of contracts for pilot production runs will begin in the spring with the pilot run scheduled to begin in the first quarter of FY98.

*Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Wave-front control of solid state lasers using an optically addressed light valve in an adaptive optics loop and applications to ultra-intense pulses.

J.-C. Chanteloup, A. Migus

Laboratoire pour l'Utilisation des Lasers Intenses, (LULI) CNRS UMR 7605,

Ecole Polytechnique, 91128 PALAISEAU Cedex, France

Telephone: 33 1 69 33 41 12 Fax:33 1 69 33 30 09

B. Loiseaux, J.-P. Huignard

Laboratoire Central de Recherche, Thomson CSF, 91404 ORSAY Cedex, France

High energy intense lasers are difficult to focus close the diffraction limit because of phase-front aberrations induced in the optics and amplifiers. This may be an issue in applications where the pulses need to be focused near the diffraction limit such as in ultra-intense femtosecond laser-matter interactions. We describe here a new technique that we have implemented and which significantly improves the focal spot quality by correcting the wave front even from highly distorted beam. This correction method is based on an adaptive optical technique using an optically addressed light valve (OALV)[1] and an achromatic three wave lateral shearing interferometer (ATWLSI)[2]. Results with strongly aberrated beams focused close to the diffraction limit will be presented.

Large phase distortions (several waves) are common in high energy solid state laser chains. One particular additional difficulty with femtosecond lasers is due to the very short coherence length making it impractical to use conventional interferometry based sensors. Then, achromaticity and high dynamic range are the two requirements to be matched by a wave front detector. This is why we have developed a detection scheme based on an ATWLSI, while the correction part is performed with an OALV developed at Thomson-CSF. This latter device, which acts as an electro-optical adaptive phase plate, is a spatial light modulator relying on liquid crystal technology. This valve uses bulk monocrystalline $Bi_{12}SiO_{20}$ (BSO) as both the photoconductive material and as one of the substrates supporting a liquid crystal layer (see Fig.1). When addressed optically with incoherent light ($\lambda_{Writing}$<500nm), the photoconductive properties of BSO allow a local transfer the voltage on the liquid crystal layer. Then, over the entire valve aperture, the liquid crystal exhibits spatial index variation proportional to the incoherent light spatial distribution. An IR beam passing through this active phase plate will have its wave front controlled according to the voltage distribution. Depending on the thickness of liquid crystal, several wavelengths phase deformation can be generated. Transverse resolution of the OALV ensures the control of 100*100 pixels over the beam aperture. Optical addressing is performed by imaging a programmable mask on BSO. In our experiment, the mask is displayed onto an Electrically Addressed Liquid Crystal Active Matrix (EALCAM) used between cross polarizers (see Fig.2). The transmission of each pixel of this mask is controlled according to the error signal given by the ATWLSI.

The experimental set-up uses a feed-back loop between the ATWLSI and the OALV[3]. Depending on the shape of the measured phase, a conjugate active phase plate is generated with the valve. Figures 3 shows the experimental results of the wave front correction experiment. Phase profile shown on the top-right exhibits a $\lambda/5$ peak-to-peak distortions ($\sigma_\Delta = \lambda/47.2$ rms) demonstrating experimentally nearly diffraction limited focal spot (Strehl ratio = 96%). Original wave front quality was 1.7λ peak-to-peak with $\sigma_\Delta = \lambda/2.8$ rms with a Strehl of 25%. We will also show results obtained with nanosecond pulses emitted from a Nd:Yag Q-switched laser, with fluence in the 10-100mJ/cm² range on the device, and present the first results obtained on the subpicosecond 100 Terawatt Ti:sapphire/Nd:glass laser facility developed at LULI.

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Figure captions :

Fig. 1: Operating principle of the Optically Addressed Light Valve: Local BSO illumination spatially modulates the Liquid Crystal birefringence converting a spatial intensity modulation at λ_W to a spatial phase modulation at λ_R.

Fig. 2: Experimental Set-up showing the Electrically Addressed Liquid Crystal Active Matrix (EALCAM) and the Optically Addressed Light Valve (OALV) in a feed back-loop.

Fig. 3: 3D views of aberrated and corrected wave fronts (pupil diameter is about 6 mm).

Fig. 4: 3D and top views of original (Strehl ratio = 25%) and improved (Strehl ratio = 96%) intensities distribution in the focal plane.

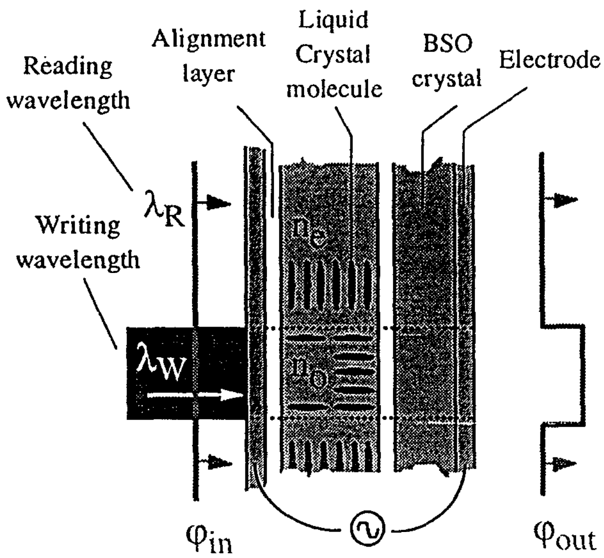


Figure 1.

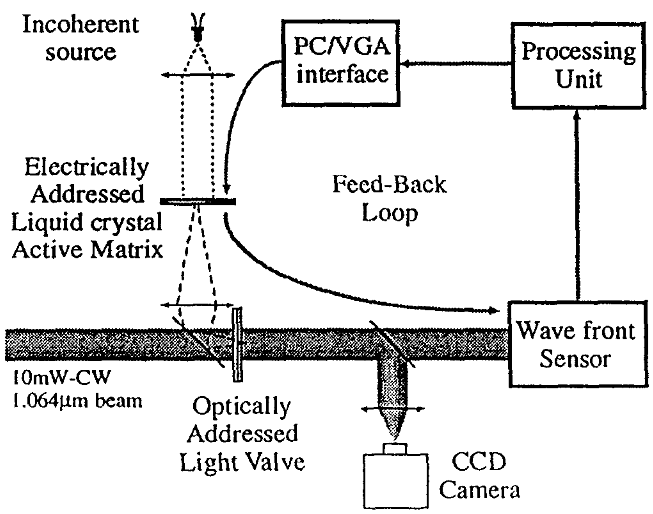
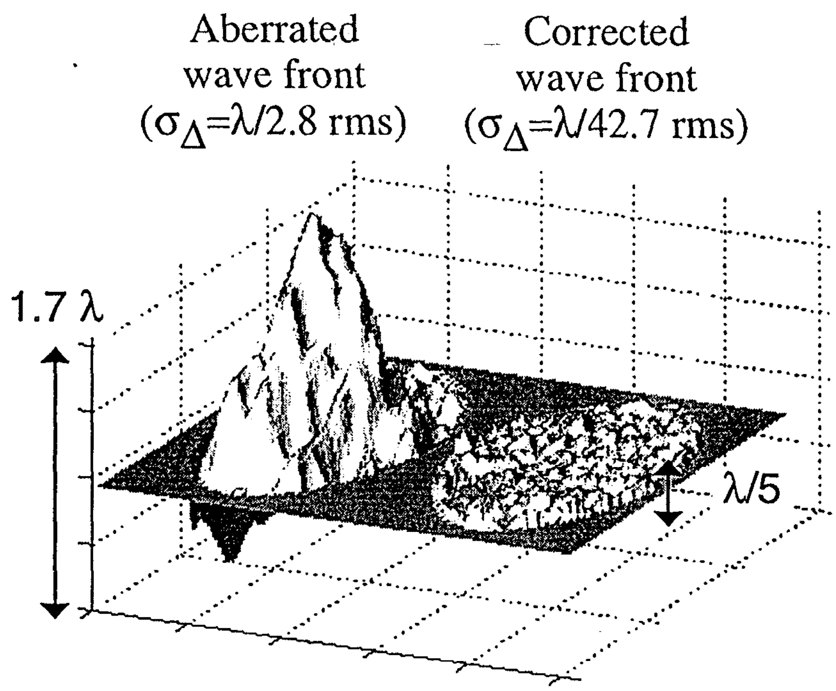
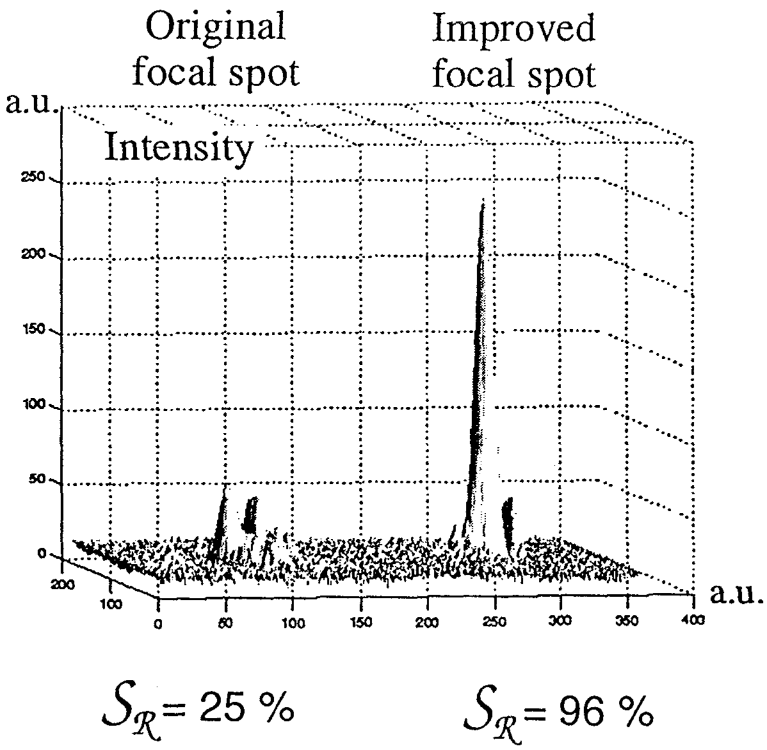


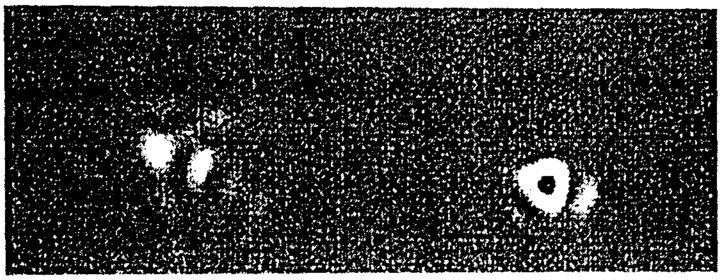
Figure 2.



Aberrated wave front (σ_Δ=λ/2.8 rms)
Corrected wave front (σ_Δ=λ/42.7 rms)
1.7 λ
λ/5



Original focal spot
Improved focal spot
a.u.
Intensity
250
200
150
100
50
0
200
100
0
50
100
150
200
250
300
350
400
a.u.
$S_{\mathcal{R}}$= 25 %
$S_{\mathcal{R}}$= 96 %



Focused Intensities of 10^{20} Wcm^{-2} with the Upgraded Vulcan CPA Interaction Facility

CN Danson, R Allott, S Angood, J Collier, A Damerell, CB Edwards, J Govans, S Hancock, P Hatton, MHR Hutchinson, MH Key*, C Hernandez-Gomez, W Lester, D Neely, P Norreys, M Notley, D Pepler, C Reason, DA Rodkiss, M Trentelman, T Winstone, R Wyatt and B Wyborn

Central Laser Facility, Rutherford Appleton Laboratory,
Chilton, Didcot, Oxfordshire, OX11 0QX
Tel: 01235 446340 Fax: 01235 445888
e-mail: c.danson@rl.ac.uk
* Current Address : Lawrence Livermore National Laboratory, California, US

Vulcan is a multi-beam, Nd:glass, ultra-high power laser facility which has recently been upgraded to deliver target irradiances up to 10^{20} Wcm^{-2}. This performance is achieved using Chirped Pulse Amplification (CPA)[1] to deliver a high energy, ultra-short pulse within a good quality (3x diffraction limited) beam.

In the CPA technique the pulses are stretched, amplified, compressed and focused on target using reflective optics. The pulse compression stage uses a pair of large aperture (400 mm x 190 mm) diffraction gratings. Parabolic focusing optics are used to produce a focal spot of ~10 microns diameter.

Details of the new target chamber designed specifically for multi-geometry CPA interaction experiments will be presented. This chamber accommodates the broad spectrum of experiments performed at the CPA facility. This includes: ultra-high intensity gas and solid target interactions, high harmonic generation, X-ray lasers; ICF studies and laser based particle acceleration experiment.

We describe details of the design of the pulse stretching and compression system, the measurement and control of the pulse duration, bandwidth, energy and beam quality. The practical considerations of operating a system capable of focused intensities of 10^{20} Wcm^{-2} are discussed.

1. Strickland and Mourou, Opts Comm, Vol.56, No. 3, pp 219-222, 1985.

Abstract Submitted
for 3rd Annual International Conference on
Solid State Lasers for Application to ICF
Monterey,California
June 7-12,1998

The SG-III Solid State Laser Project

H.S.Peng and X.M.Zhang
China Academy of Engineering Physics
P.O.Box 501, Chengdu, China, 610003

D.Y.Fan
Joint Laboratory of High Power Laser and Physics
P.O.Box 800211, Shanghai, China, 201800

ABSTRACT

The SG-III laser facility, has been proposed to produce 60-kJ blue light for ICF target physics experiments and is being conceptually designed in China. A preliminary baseline design suggests that the SG-III be a 60-beam facility with an output beam size of 25cm x 25cm. The main amplifier column of 4 high by 2 wide has been chosen as a module. New laser technologies, including maltipass amplification, large aperture plasma electrode switches, fast growth of KDP, laser glass with fewer platinum grains, long flash lamps,capacitors with higher energy density and precision manufacturing techniques of large optical components have been developed to meet the requirements of the SG-III Project. In addition, numerical simulations are being conducted to optimize the optical design of the facility. The Technical Integration Line (TIL) of 4 x 2 segmented apertures as a prototype module of the SG-III has been scheduled for the next few years.

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TH3A-2

A NOVEL METHOD TO RECONSTRUCT THE WAVEFRONT OF HIGH POWER LASER BEAM

Chen, Zhe; Hu, Yongming; Zeng, Chun; Chang, Shenli
Department of Applied Physics, National University of Defense Technology
Changsha, Hunan 410073, P.R. China
E-mail: zhechen@nudt.edu.cn

Zhang, Xiaomin; Zheng, Wanguo
Institute of Nuclear Physics and Chemistry
China Academy of Engineering Physics
P.O. Box 525, Chengdu, 610003, P.R. China

The paper describes a novel method to reconstruct the wavefront with phase distortion in STARLIGHT ¢ò1012W high power laser apparatus by means of computer image processing. In experiments, the image processing of optical spots which were fired on photograph by high power laser beams through a plate with hole array. The iteration formula group was deduced to apply in the experiments. Each center of intensity of optical spots and relative drift placement was measured, and phase wavefront of high power laser was reconstructed in iteration.

Computer software made the focusing procedure of small optical beams in hole array instead of sub-lens array of normal Hartmann-Shack sensor. The method can be used to measure directly the beams of high power laser with large diameter of beam. We described the principle and the formula of the reconstruction in the paper. The method has been used in experiments of in the high power laser apparatus STARLIGHT II. The measured maximum of diameter is 200 mm, and the resolving power of reconstruction of wavefront is about 1/5.

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TUIA-4

MICROCHIP LASERS FOR THE LMJ FRONT-END

L. Fulbert, P. Kramer*, M. Rabarot, E. Molva

LETI/CEA.G - DOPT, 17 rue des Martyrs
38054 GRENOBLE Cedex 9, France
Tél : (33) 476 88 38 45, Fax : (33) 476 88 51 57, e-mail : fulbert@cea.fr

*SEGIME, 11 bd Pershing, 75017 PARIS, France

The Laser Mégajoule (LMJ) optical pulse generation system consists of 240 gain-switched Nd:YLF microchip lasers producing 1053 nm light with a single frequency operation and a linearly polarized beam. A single mode polarization maintaining fiber distributes the output of each microchip laser to electro-optic phase and amplitude modulators. A long polarization maintaining fiber carries the pulse to 240 regenerative amplifiers. We report here on novel microchip lasers for the LMJ.

Microchip lasers are very compact and very simple diode-pumped solid-state lasers. They have a monolithic cavity with mirrors directly deposited on the polished surfaces of the active laser material. The cavity can be either plane-parallel or plano-concave by etching a concave mirror on one side of the microchip laser. These lasers have a very small size (less than 1 mm^3) and can be fabricated at low cost, using collective fabrication processes such as used in microelectronics.

Nd:YLF plane-parallel microchip lasers are used in the LMJ pulse generation system because of their linearly polarized emission at 1053 nm. Due to their very small cavity length (about 1 mm), these microchip lasers have a single frequency emission and single-mode TEM_{00} operation.

For the pulsed operation, gain-switch has been chosen instead of Q-switch. For pumping the microchip laser in gain-switched regime, we use a GaAlAs diode laser emitting at 792 nm. The diode is driven with 6A current pulses well above its nominal operating current during a very short period. When it is pumped by a pulsed source, the microchip laser generates spiking pulses. Pulses of 1,6 W peak power and 65 ns pulse width have been obtained with the Nd:YLF microchip lasers. The laser emission remains linearly polarized at 1053 nm and single frequency during the pulse.

The microchip lasers are focused into a single mode polarization maintaining fiber with a silica microlens. The fiber core is about 6 μm and the microlens focal length is 800 μm. Coupling efficiencies up to 75% have been achieved in a laboratory workbench. Better results are expected by assembling the components together.

Several gain-switched microchip lasers have been built and are used in the LMJ pulse generation system. Integrated fiber coupled devices will be available in the beginning of 1998.

Laser ablative figuring of optical elements for phase control

Takahisa Jitsuno, * Keiu Tokumura and Masahiro Nakatsuka

Institute of Laser Engineering, Osaka University
2-6 Yamada-oka, Suita, Osaka 565, Japan
Phone:81-6-879-8768, Fax:81-6-877-4799
e-mail: jitsuno@ile.osaka-u.ac.jp

*Nippon Aspheric Lens Co., Ltd.
3-2-30 Minami-eguchi, Yodogawa-ku, Osaka 533, Japan
Phone:81-6-329-4567, Fax:81-6-328-5076
e-mail: tokumura@ile.osaka-u.ac.jp

A precise figuring of optics is important for obtaining high optical performances in optical devices. In ICF, a large amount of precise optics is required in large size optical elements. The micro-lens array for the control of the pumping light from laser diodes (LD) is an important element for uniform pumping of the amplifier. However, the precise figuring of optics is very difficult because the figuring process is usually made separately from the phase measurement procedure. The figuring of micro-optics such as the collimator lens for LD is almost impossible in the conventional method.

We have proposed the laser ablative figuring (LAF) of optics using very short wavelength laser (ArF excimer laser; λ=193 nm)[1,2]. In this scheme, the surface of optical plastic coated on a glass plate is ablated by laser beam for the control of the transmission or reflecting wave front.

LAF system consists an interferometer, a ArF excimer laser, a precise X-Y stage with computers for the control of the stage and for the calculation of wave front. According to the poor beam quality of ArF laser , the output beam is selected a uniform area using 4.5 mm diameter aperture. This beam is projected directly on to the work peace for the ablative figuring. A variable attenuator of the beam is used to control the laser intensity. At the start of the process, the wave front of the substrate is measured using the phase shift interferometer. The measured wave front is compared with the desired shape (in this case, flat or spherical shape), and the computer generates the map of shooting number of pulses on the substrate. After the irradiation of the laser pulses, the wave front is measured again. These procedures are repeated until the phase error reaches to the tolerable level. Normally, this feedback loop is repeated for 2 or 3 times for obtaining the results described in this paper.

Glass-plastic hybrid substrates of 5 cm in diameter were used for the flat and spherical surface generation. The fluence of the irradiating laser pulse was 45 mJ/cm^2. This fluence is chosen because the surface roughness is minimum at this fluence level. The scan increment is 0.36 mm for X and Y direction. The wave front distortion at the starting period is 3.0 λ for flat surface generation, and 2.5 λ for spherical surface generation, respectively. The final wave front distortion for the flat surface is 0.17 λ for the 90 % area. In the case of spherical surface, the aspheric component is also less than 0.2 λ. The surface roughness is almost the same level before and after the ablation. This LAF process is done under the automatic control using computers. We believe that this is the first demonstration of the fabrication of precise optics with continuous surface using LAF method.

The accuracy level achieved here is high enough for the general purpose optics. The success of the surface shape of optics using LAF should be very important for the practical application because the phase distribution of any shape can be made under the control of computer. Since the proof of principle (POP) experiment has been done successfully, we are now trying to apply LAF method to the micro-lens fabrication for LD array.

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Baseline Design of Proposed AWE 100 TW Solid State Laser System

J A McMordie, AWE, Aldermaston, Reading, Berks., RG7 4PR, UK

Tel. (44)(0)1734 825001 Fax (44)(0)1734 824844

ABSTRACT

To meet the future requirements of the AWE Plasma Physics Programme, design studies are being conducted for a 100 TW Nd doped glass laser system converted to the third harmonic. The baseline design of the proposed system will be presented. The AWE laser is based on technology developments for the US National Ignition Facility, NIF, and will share many common features. The proposal is for a 32 beam laser system which is a sub-set of the 192 beam NIF.

The 32 beams are clustered as 4 beamlines, each beamline configured in a 4x2 array following the NIF laser design. The UK unique features of the design will be highlighted. This includes the physical layout of the system and the beam transport onto target. The laser is optimally configured for indirect drive experiments including provision for diverting selected beams for X-ray backlighter purposes.

Current Status and Future Development of the Vulcan High Power Nd:glass Laser

M.H.R. Hutchinson, C.N. Danson, C.B. Edwards, D Neely, B Wyborn
Central Laser Facility, Rutherford Appleton Laboratory
Chilton, Didcot, Oxfordshire, U.K. OX11 0QX

Abstract

We report on the current status of the 5 year Vulcan development programme and outline plans for the future enhancement of the facility to the Petawatt level.

The ultra-high irradiance capability of the Vulcan Nd:glass laser has been upgraded to the 10^{20}Wcm^{-2} level using Chirped Pulse Amplification [1]. The system routinely delivers 50TW to target in a sub-picosecond pulse with ~ 3 x diffraction limited beam quality in support of a wide ranging experimental programme. The ultra-short pulse beam is synchronised to the six main interaction beams which provide up to 1.5kJ at 1μm for plasma production, compression, and probing. A further 500J beamline is available for X-ray backlighting [2].

The scientific programme planned for Vulcan over the next 3 years requires the availability of sub-ps, near diffraction limited multi-Terawatt beams at the 2nd and 3rd harmonic, higher main beam energy and further development of the CPA beamline to the Petawatt level. Progress in these areas is presented and plans for the facility over the next three years are discussed.

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TV2A-3

AN OPTICAL PULSE-SHAPING SYSTEM BASED ON APERTURE-COUPLED STRIPLINES FOR OMEGA PULSE-SHAPING APPLICATIONS

M. D. Skeldon, A. V. Okishev, R. L. Keck, W. Seka

Laboratory for Laser Energetics
University of Rochester
250 East River Road
Rochester, NY 14623-1299

and

S. A. Letzring

Los Alamos National Laboratory
Los Alamos, NM 87545

Pulsed-laser systems emit optical pulses having a temporal pulse shape characteristic of the particular type of laser design. Advances in ICF technology have produced laser-pulse-shaping systems where the laser temporal profile can be specified in advance and controlled to a high degree of accuracy.[1] LLE's OMEGA pulse-shaping system consists of many components:[2] A cw-mode-locked (CWML) laser seeds a regenerative amplifier whose output is steepened with an SBS reflection.[3] The SBS pulse is sent to a fiber distribution system where it illuminates photoconductive switches that produce shaped electrical waveforms. The electrical waveforms are sent to optical modulators to shape optical pulses. This paper discusses a greatly simplified pulse-shaping system based on aperture-coupled striplines (ACSL) that eliminates the need for the above components while alleviating many of the shortcomings of the present system.

The pulse-shaping system discussed here is based on a four-layer, four-port ACSL. The ACSL is modeled as a four-port electrical directional coupler. An exploded view of a practical device is shown in Fig. 1. In operation, a square electrical pulse is launched into port 1 and travels along electrode 1 to the terminated port 2. An electrical signal is coupled through an aperture to electrode 2 in the backward direction and exits at port 4. By properly varying the width of the coupling aperture along the length of the coupling region, any desired temporally shaped electrical waveform can be generated at port 4 and sent to an electro-optic modulator for pulse shaping. The ACSL system's key operational advantage that allows the above simplification is that the shaped electrical waveform from the ACSL exits from a different port than the port used to input the square electrical pulse. Consequently, any suitable (commercially available) electrical square pulse generator can be used to generate shaped electrical waveforms. The ACSL pulse-shaping system has an inherently high contrast (optical pulse amplitude to prepulse noise) and can be accurately timed to the OMEGA master clock. Timing jitter between a 76-MHz CWML-laser optical pulse and the shaped optical pulse is measured to be less than 10 ps.

The overall modeling of this pulse-shaping system includes depletion of the input square pulse in the ACSL due to coupling to electrode 2 and the finite response time of the optical modulators. The outputs at each port of several ACSL's have been measured and show excellent agreement to our model. Electrical and optical waveforms with 50- to 100-ps structure over a 1- to 5-ns envelope have been produced. The modeling, design criteria, fabrication, and test results for ACSL's that allow one to produce specifically shaped optical pulses are discussed in detail.

This work was supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under Cooperative Agreement No. DE-FC03-92SF19460, the University of Rochester, and the New York State Energy Research and Development Authority. The support of DOE does not constitute an endorsement by DOE of the views expressed in this article.

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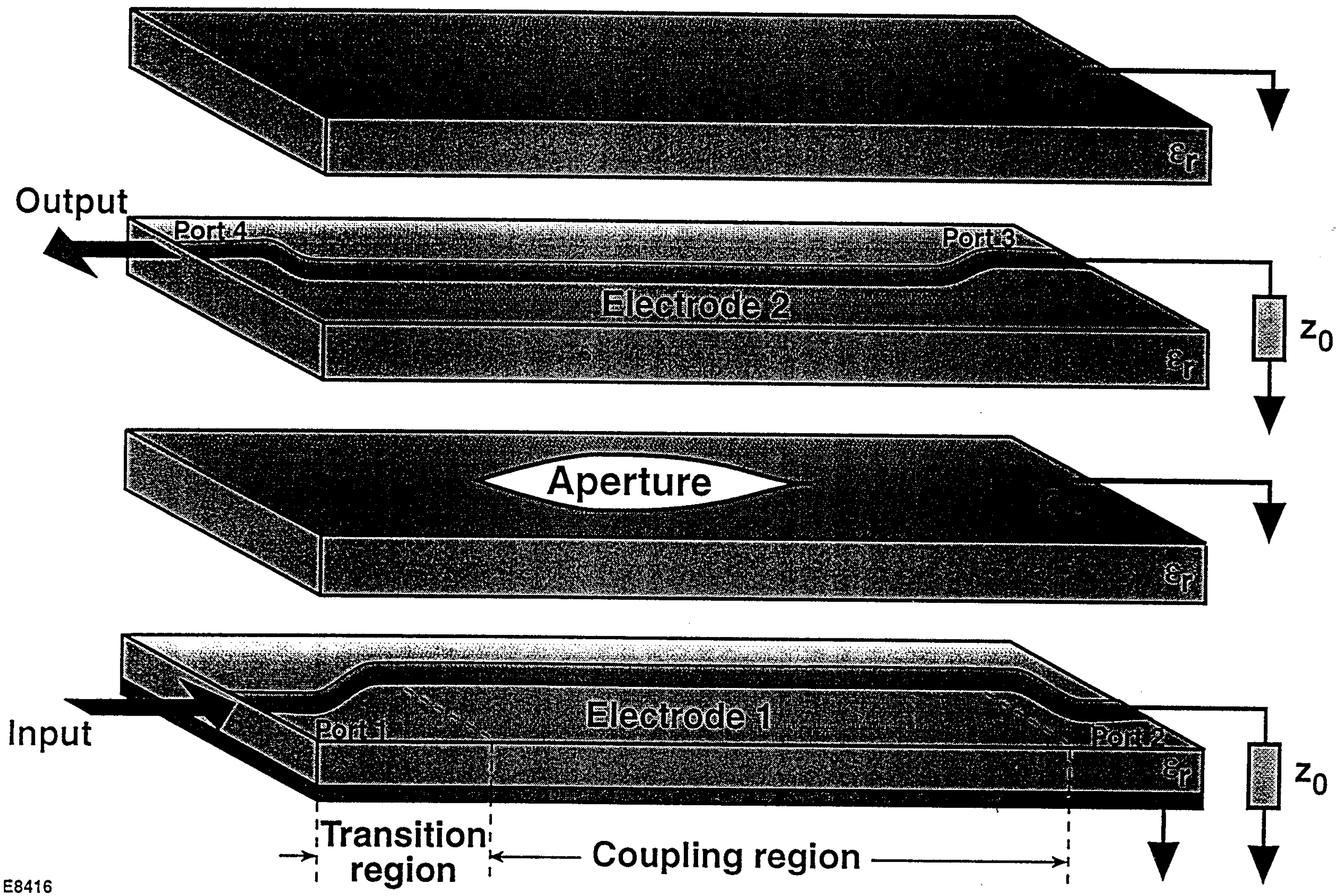
Figure Caption

Fig. 1 Exploded view of an aperture-coupled stripline (ACSL) for OMEGA pulse shaping.



Output
Port 4
Port 3
Electrode 2
ε_r
z_0
Aperture
Electrode 1
Input
Port 1
Port 2
Transition region
Coupling region

E8416

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M1-2

OVERVIEW OF THE NATIONAL IGNITION FACILITY PROJECT

J. A. Paisner and J. R. Murray
Lawrence Livermore National Laboratory
P. O. Box 808, L-488, Livermore, CA 94551
phone (925) 422-6211, fax (925) 423-6212
paisner1@llnl.gov, jrmurray@llnl.gov

The United States Department of Energy has established a project to construct a National Ignition Facility (NIF) for inertial confinement fusion (ICF) and other research into the physics of high temperatures and high densities. The facility will contain a neodymium-glass laser capable of irradiating targets at an energy of 1.8 MJ and peak power of 500 TW at the third harmonic (351nm wavelength) in a pulse shape suitable for an ICF ignition target. This paper presents a brief overview of the facility.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

SHOT RATE OF THE NIF LASER SYSTEM*

Kenneth R. Manes, Shamasundar N. Dixit, and Steven B. Sutton
Lawrence Livermore National Laboratory
P.O. Box 808, L-465, Livermore, California, U.S.A. 94551
(510) 423-6207 FAX (510) 424-5195
manes1@llnl.gov

ABSTRACT

The National Ignition Facility (NIF) system will have many different users. The system is being designed to have an initial shot rate of eight hours and, if the need arises, to increase the shot rate in the out-years to four-to-six hours.

It is phase errors that result from repeated firings of the flashlamps that determine the focal spots of the individual 192 beams. Flashlamp cooling and radiative cooling of the pump cavity are used to reduce the phase errors to the level needed to produce the desired focal spot.

A flowdown analysis that identifies the major contributors to these cummulative phase errors is presented. Merthods for increasing the shot rate in the out-years is also discussed.

*Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

Getting One-Ton, Phone-Booth-Sized Optic Modules into the World's Largest Laser

S. Yakuma and E. Grasz (with S. Bahowick, A. Rowe, J. Sander, D. Swan,and D. Tiszauer)
Lawrence Livermore National Laboratory, P.O. Box 808, L-447, Livermore, CA, 94551
(510) 423-6210—Fax (510) 423-7390—yakuma1@llnl.gov
(510) 423-6556—Fax (510) 423-7390—grasz1@llnl.gov

ABSTRACT

The National Ignition Facility (NIF), currently under design and construction at Lawrence Livermore National Laboratory (LLNL), will be the world's largest laser when complete. The NIF will use about 8,000 large optics of 26 different types to focus up to 192 laser beams on a dime-size target. The demands on all aspects of NIF operation are exacting, making its engineering and design a monumental task. Among the many coordinated efforts in this task is the transport and handling of the various beamline optic modules, more specifically their installation into the laser system.

The automated installation of the thousands of optic modules that make up the NIF laser will be a complex operation. Each laser component will be packaged into a line-replaceable unit (LRU) made up of a mechanical housing, laser optics (lenses and mirrors), utilities, actuators, and kinematic mounts. Given the constraints of the operating environment, such as high cleanliness and limited space, the tasks associated with LRU interchange require unique and flexible hardware system designs. These designs must be capable of manual involvement, semi-autonomous operations, and full autonomous functions.

The primary focus of this paper is the innovative Laser Bay delivery system designs that accommodate the diverse and often conflicting design requirements. These systems use a novel and versatile automated guided vehicle (AGV) as the transport vehicle. Coupling this unique transport system with a stable canister design and automated insertion-hardware designs creates an integrated delivery system that ensures efficient, safe, and clean transport of the NIF's precisely aligned LRUs.

In this paper, we also present both the design philosophy for the NIF (to modularize the laser optical components) the design challenges, performance trade-offs and the aggressive schedules. We will also discuss how the lessons learned and data acquired from the Prototype systems have influenced the design to date.

Precision Assembly and Alignment of Large Optic Modules for the National Ignition Facility

P. Hurst and E. Grasz (with H. Wong, E. Schmitt, and M. Simmons)
Lawrence Livermore National Laboratory, P.O. Box 808, L-447, Livermore, CA, 94551
(510) 422-0246—Fax (510) 423-7390—hurst2@llnl.gov
(510) 423-6556—Fax (510) 423-7390—grasz1@llnl.gov

ABSTRACT

The National Ignition Facility (NIF), currently under design and construction at Lawrence Livermore National Laboratory (LLNL), will be the world's biggest laser when complete. The NIF's large optics will be assembled into modules, known as Line Replaceable Units (LRUs), and will be the biggest ever assembled in a clean room environment. Some of the assemblies will weigh as much as 3,000 lb.

The National Ignition Facility has an aggressive schedule for initial installation and activation of the multi-pass, 192 beam, high power, neodymium-glass laser. The optics will be assembled and aligned in the NIF Optics Assembly Building (OAB), adjacent to the huge Laser and Target Area Building (LTAB), where they will be installed. To accommodate this schedule rapid assembly and alignment of large aperture optics into LRUs will occur through the use of automated handling, semi-autonomous operations and strict prototcols. The OAB will have to maintain rigorous cleanliness levels, achieve both commonality and versatility to handle the various optic types, and allow for just-in-time processing and delivery of the optics into the LTAB without undoing their strict cleanliness and precise alignment.

This paper describes the project's design philosophy of modularity and hardware commonality. We present the many design challenges we have tackled, as well. For example, an LRU typically includes a mechanical housing, laser optics (lasers and mirrors), utilities, and actuators; the optics are fragile and require delicate handling; and the mechanical parts to be cleaned vary greatly in geometry, surface finish, and material, and range in size from tiny machine screw parts to frame-like mechanical structures as long as nine feet. Of course, we also present our solutions.

We describe in detail how, by using a mixture of commercially available and newly designed equipment, we have developed unique systems for assembly and alignment, inspection and verification, and LRU loading and transfer. We also describe the performance trade-offs, the stringent cleanliness verification requirements, and the prototyping accomplishments achieved to date.

Submission for Third Annual Solid State Lasers for Application to Inertial Confinement Fusion, June 7-12, 1998, Monterey, CA

Abstract Title: NIF Integrated Computer Control System

Authors: P. J. Van Arsdall, R. C. Bettenhausen, F. W. Holloway, R. A. Saroyan, and J. P. Woodruff

Address: Lawrence Livermore National Lab
PO Box 5508 MS L-493
Livermore,. CA 94551
FAX: 510-422-1930
Email:

Oral presentation preferred

Abstract

Risks associated with computer control systems are significant for complex scientific facilities such as the NIF. Although distributed architectures have demonstrated their utility on other large projects, the scale and planned longevity of new machines stresses conventional engineering approaches.

The NIF design team is developing the Integrated Computer Control System (ICCS), which is based on a general object-oriented framework applicable to event-driven control systems. The framework provides an open, extensible architecture that can be maintained and upgraded for decades. It is also sufficiently abstract to allow future control systems to take advantage of this work.

The ICCS architecture consists of a layer of several hundred front-end processors (FEP) coordinated by a supervisory layer. Facility computers are networked over a hybrid configuration of switched fast Ethernet and asynchronous transfer mode (ATM). The ATM network segment carries digital motion video from 600 TV sensors to operator consoles. The ICCS also includes an industrial controls segment that uses programmable logic controllers to operate more traditional equipment such as vacuum controls and safety interlocks.

The supervisory layer, hosted on UNIX workstations, integrates various subsystems for experiment planning, operator control, automated sequencing, analysis, and archiving. Supervisory software is constructed by extending the reusable framework components for each specific application. The framework incorporates services for database persistence, system configuration, graphical user interface, status monitoring, event logging, scripting language, alert management, and access control. More than twenty collaborating software applications (e.g., power conditioning, laser diagnostics, and alignment) are derived from the common framework.

FEP units interface to over 40,000 control points attached to VME-bus, VXI-bus, and PCI-bus crates. Typical control points are stepping motors, transient digitizers, and photodiodes. The VxWorks real-time operating system is used to embed functions in the FEP.

The framework is interoperable among different kinds of computers and functions as a plug-in software bus by leveraging a common object request brokering architecture (CORBA). CORBA transparently distributes the software objects across the network; software objects representing control points derive the distribution mechanism from the framework and plug into the CORBA bus. Because of the pivotal role played in the ICCS architecture, CORBA was tested to evaluate potential limitations and ensure performance would be adequate. A discrete event simulation was used to verify the architecture's performance.

Software development is managed under an engineering methodology that covers the entire product life cycle. The object-oriented design is captured in an integrated design tool that automatically generates code specifications. Ada 95 is being used to enhance the reliability and maintainability of the software in view of periodic software upgrades expected during the 30-year life of the NIF. Both Ada and CORBA are designed to be portable as computer equipment evolves.

Ongoing development follows iterative tactics in which three prototypes are planned. The first phase will deliver vertical slices of all applications from the FEP to the supervisory layer. Subsequent phases will be constructed during 1999 leading toward first deployment in the facility in the year 2000, when the first 8 of the 192 beams will be operated.

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*Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

Stability of Optical Elements in the NIF Target Area Building

David J. Trummer, Richard J. Foley, Gene S. Shaw

Lawrence Livermore National Laboratory
P.O. Box 808, L-126
Livermore, California, USA 94550
(510) 423-8848
FAX (510) 424-2135
E-MAIL: trummer1@llnl.gov

Al McDonald

Sandia National Laboratory
Livermore, California, USA 94550

The Target Area Building (TAB) of the National Ignition Facility (NIF) is 300 feet long, 100 feet wide, and 100 feet tall and is comprised of a cylindrical target bay and two switchyard space frames. The reinforced concrete target bay houses the target chamber, target positioner, turning mirrors, final optics assemblies, and diagnostics, while the steel switchyard space frames support turning mirrors and diagnostic equipment. Within the TAB, the 192 independent laser beams of the NIF laser system are required to be accurately positioned. In order to satisfy the engineering system requirement for optical system positioning (stability on target), the TAB must provide a stable platform for optical elements before and during a shot. This paper summarizes the stability analyses that were performed in support of the TAB and optical system design.

Sources that influence optic stability are structural excitations, such as ambient and wind induced vibrations, and thermal transients, such as diurnal and HVAC temperature changes. A positioning error budget has been developed for the NIF project for use in the design and evaluation of structures which support optical elements. To satisfy the error budget requirements, vibrational stability will be achieved through a combination of facility design, optic support structure design, and passive damping. Thermal stability will be accomplished by using high thermal-mass concrete structures, conditioned air flow, and a reduction of heat sources.

Finite element analysis has been used to evaluate the design of the TAB and optical support structures. A detailed structural model of the TAB that includes the target positioner, target chamber, turning mirrors, and diagnostics, has been used for stability evaluations. Finite element analyses covering ambient ground vibration, thermal loads, pressure fluctuations, and wind excitations have demonstrated that the current design of the TAB provides a stable platform for maintaining beam alignment.

Work performed under the auspices of the US Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

Vendor-based laser damage metrology equipment supporting the National Ignition Facility

S. Schwartz, J. F. Kimmons, M. R. Kozlowski,
L. M. Sheehan, C. J. Stolz, J. H. Campbell
Lawrence Livermore National Laboratory
P.O. Box 808, L-496
Livermore, CA 94551-0808

ABSTRACT

A sizable laser damage metrology effort is required as part of the production and installation of the optics in the 192 beam NIF laser. The large quantities, high damage thresholds, and large apertures of the NIF polished and coated optics necessitates vendor-based metrology equipment to assure component quality during production. This equipment must be optimized to provide the required information as rapidly as possible and with limited operator experience. The damage metrology tools include: 1) platinum inclusion damage testers for laser slabs, 2) laser conditioning stations for mirrors and polarizers, and 3) mapping and damage testing stations for 3w transmissive optics. Each system includes a commercial YAG laser, a translation stage for the optics, and diagnostics to evaluate damage. The scanning parameters, optical layout, and diagnostics vary with the test fluences required and the damage morphologies expected. This paper describes the technical objectives and milestones involved in fulfilling these metrology requirements at multiple vendors.

Work performed under the auspices of the U. S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-ENG-48.

3ω Damage Threshold Evaluation of Final Optics components using Beamlet Mule and Off-line Testing

M. R. Kozlowski, S. Maricle, R. Mouser, S. Schwartz,
P. Wegner, T. Weiland, J. H. Campbell
Lawrence Livermore National Laboratory
P.O. Box 808, L-496
Livermore, CA 94551-0808

ABSTRACT

Large-aperature 3ω lenses and flats were evaluated for laser damage performance at NIF-like fluences. The optics evaluated were manufactured by several potential NIF optics vendors. Testing included: 1) mapping of surface and bulk artifacts using a Damage Mapping System (DMS) with a detection limit of approximately 10μm; 2) raster-scan damage testing on a 3ω Damage Test Station; 3) full-aperature illumination on the Beamlet Mule in campaign of at least 20 high fluence shots; 4) remapping of the optics after each damage test using DMS. Information gained from tests include damage density and growth rate as well as correlation of damage sites to mapped optic defects, i.e. damage precursors. The tests will evaluate 3 to 5 lenses and 3 to 4 debris shields/defractive optics plates. The primary objective of the test in to correlate off-line damage test results with optic damage severity in NIF-like conditions such correlations will help us to clarify optics production QC procedures and to make optics liketime predictions for NIF environments.

Work performed under the auspices of the U. S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-ENG-48.

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THE SIGNIFICANCE OF STIMULATED BRILLOUIN AND RAMAN BACKSCATTER FROM THE TARGET AS A SOURCE FOR OPTICS DAMAGE

B. Langdon, B. MacGowan, R. Berger, S. Dixit, M. Feit, J. Hendrix, D. Hinkel
R. Kirkwood, K. Manes, J. Miller, J. Moody
J. Murray, T. Parham, C. Stolz, and B. Van Wonterghem

Lawrence Livermore National Laboratory
University of California
Box 808, L-472
Livermore, CA 94550
fax: (925) 423-9969 e-mail: blangdon@llnl.gov

We are assessing the possibilities for damage to the silica vacuum window and to mirrors in the NIF/LMJ lasers due to stimulated backscatter from the target. Spatial and temporal modulations in the backscatter would increase the damaging fluences above the average. If the backscatter were phase-conjugated, there would be no spatial modulation. However, according to calculations with the laser-plasma modeling code F3D, the backscatter is not phase conjugated but shows speckle structure in the near field and is well collimated. Time dependence of the backscatter may mitigate thermal damage by moving the bright speckles and might stabilize filamentation in the silica. This work is ongoing and will be fully reported at the meeting.

Work performed under the auspices of the United States Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.

SG-II Solid-State Laser ICF System

Gangyao Xiao, Dianyuan Fan, Zunzi Lin, Yuxia Zhen, Jian Zhu, Fengqiao Liu, Shaohe Chen, Jianqiang Zhu, Shiji Wang and Ximing Deng

National Lab on High Power Laser & Physics
Shanghai Institute of Optics & Fine Mechanics

P. O. Box 800-211, Shanghai 201800, P. R. China
Tel: 86-21-5952 8355, Fax: 86-21-5952 8812
Email: dyfan@fudan.ac.cn

Abstract

The SG-II laser facility have been built for researches on high power physics such as x-ray laser, ICF etc. The solid-state laser facility contains 8 beams with a beam size of 245mm. The goal of SG-II is to produce energy of 2.4KJ at 3 ω (351nm). This paper will introduce some improvements in system operation including,

- Temporal-spatial-transform pulse shaping technology to tune the pulse width from 350ps to 1ns.
- Co-axial double pass disk amplifier without switch to obtain 95 percent of the total energy.
- CCD beam alignment technology and beam pointing precision.
- Two-beam co-line focus and two series coupling targets technology is succeeded in X-ray experiment.

Preliminary Design of Target Area Optical Layout for SG - Ⅲ Facility

X. Wei, Z. Shi, X. Zhang and H. Peng

Laboratory for Laser Fusion,
Southwest Institute of Nuclear Physics and Chemistry
P.O.Box 525-80, Chengdu. 610003, P.R.China
Fax: 86-(816)-2271598

A preliminary structure of the target area overall optical layout has been developed by computer simulations according to the requirements of both the physics experiments and the SG -III laser facility itself. A computer code has been developed and simulations have been conducted to design the target area optical layout for both direct and indirect drive configurations, respectively. The number and location of the turning mirrors from the output lens of the transport spatial filter to the target chamber have been initially decided, and the machanical interventions of optical paths have also been solved. The main aspects are as follows:

*1. **Optical layout for indirect drive.*** 60 laser beamlets are divided into six groups, illuminating the target from both the top and bottom poles of the chamber. Three cones symmetrically illuminate target from each side. The incident angels to the hohlraum axis are listed as follows:

- Inner cone: 30 degree
- Middle cone: 45 degree
- Outer cone: 55 degree

*2. **Optical layout for direct drive.*** The target is symmetrically illuminated by 60 laser beamlets in the 4 π space.

3. Locations and angles of turning mirrors

The 60 laser beams are grouped in the switchyard and then led to the target by four turning mirrors. Optical outlays have been considered to avoid mechanical interference and to provide enough space for installation. Beams for three cones of each side are divided into three layers vertically with a space of 1.5m between each layer. The final three turning mirrors for each beam are located at the same level.

The reflection angles of the mirrors in the switchyards and the first turning mirrors are 45 degrees. The angles of the rest turning mirrors are less than 45 degrees.

Optimization and Development of a Single-Segment Amplifier

W. Zheng, X. Zhang, Y. Chunyu, S. He, Y. Du, X. Wei,
Y. Man, Z. Lin, and H. Peng

Laboratory for Laser Fusion
Southwest Institute of Nuclear Physics and Chemistry
P.O.Box 525-80, Chengdu. 610003, P.R.China
Fax:086-(816)-2271598

A Single-segment Amplifier (SSA) has been built in our laboratory to test phosphate Nd: glass and xenon flashlamps, and also to check the code for simulating the energy transferring in disk amplifier.

Monte-Calo mathod and ray-tracing are used to calculate the flashlamp light fluence and ASE in disk amplifier. Both power conditioning and flashlamp model are considered in the code. The SSA is consisted of three phosphate glass disks, variable numbers of flashlamps and different- shape reflectors for different purposes.

The experiments were taken into two steps. First, we used old power system with 96 μ F and 450 μ H to test the characters of new laser glass developed in China to increase the storage efficiency. Second, we optimized the power system and flashlamps to get better results and to check the code.

More than 2% storage efficiency and 5%/cm small signal gain with the pumping density of about 9J/cm^3 are obtained using the new phosphate glass and flashlamps. From these results, we have predicated the performances of 4×2 amplifier which will be built in the near future in our laboratory.

Preliminary Design of Technical Integration Line (TIL) for SG-III Laser Facility

X. Zhang, D. Fan, F. Jing, Z. Shui,
X. Wei, W. Zheng, Q. Zhu, and H. Peng

Laboratory for Laser Fusion
Southwest Institute of Nuclear Physics and Chemistry
P.O.Box 525-80, Chengdu. 610003, P.R.China
Fax: 86-(816)-2271598

In this paper, we present the preliminary design of Technical Integration Line(TIL). TIL is a full scale 4 x 2 module of Shenguang-III(SG-III) laser facility with two-aperture(25 x 25cm^2) 3 ω output of 3.0kJ in a temporally shaped pulse of 1.0～3.0ns. The goal of TIL is to demonstrate the laser technology of the proposed SG-III. TIL will be operated at 5.0J/cm^2 in a 1.0ns output pulse and consisted of front-end, pre-amplifier stage, main amplifier stage, diagnostic target system and optical control system.

The optical scheme of a four-pass main amplifier(A1) and a booster amplifier(A2) have been chosen. The clear aperture of amplifier is 30×30cm^2, and the number of Nd:glass disks in two amplifiers are optimized in system design. Two spatial filters are inserted in the system to remove high spatial frequencies from the beam, and SF1 is Multi-pass spatial filter and SF2 is transport spatial filter. In order to correct the output wavefront for static and dynamic wavefront aberrations of disk amplifiers, a deformable mirror system are used in main amplifier stage of TIL.

It is different from the French Megajoule Laser(MJL) that the small aperture laser beam from PA is injected into the cavity through SF1, and is amplified by A1 for the first two passes. The beam reverser in SF1 uses small mirrors and lenses to redirect the beam for another two passes. The beam aperture is 20×20cm^2 in A1 and then expands to 25×25cm^2 by SF1 to increase filling factor of A2. A large aperture plasma electrode Pockels Cell PC2 is inserted between CM and A1 to isolate backward beam or pencil beam in the system after the main pulse and a small Pockels Cell is used in beam reverser to suppress parasitic oscillations in the cavity before the main pulse. Thus, both Pockels Cells operate in static state to reduce difficulties in developing large aperture Pockels Cell and cost. There is only one large reflecting mirror in the cavity of A1 and the alignment precision and stability of the system can be increased.

Research on Multi-pass Slab Nd:glass Amplifier

Z. Sui, Y. Liang, Q. Liu, X. Tang,
H. Liu, X. Zhang and Y. Man

Laboratory for Laser Fusion
Southwest Institute of Nuclear Physics and Chemistry
P.O.Box 525-80, Chengdu. 610003, P.R.China
Fax:086-(816)-2271598

The aim of this work is to develop a repetition slab Nd:glass amplifier with an energy output of Joules. The main subjects include:

(1) A high repetition slab Nd:glass amplifier has been built. After that, some important properties of the amplifier, such as the small signal gain, gain distribution, thermal effect, storage energy and efficiency, etc., have been theoretically analyzed and experimentally studied. One of the results shows that the maximum energy storage efficiency is up to 2.1%.

(2) A multi-pass amplifier system has been built by using such slab amplifiers. And then, some properties of the system have been theoretically analyzed and experimentally researched, such as architecture, energy flounce distributions, gain characteristics, beam transportation, ASE and parasitic oscillations, etc. We have been found out an efficient method to suppress the ASE and parasitic oscillations. An output beam of 6 times diffraction limits with an energy up to 1J has been obtained by such a system.

Modeling of Laser Knife-Edge and Pinhole Experiments*

C. D. Boley, K. G. Estabrook, J. M. Auerbach, M. D. Feit, and A. M. Rubenchik

University of California
Lawrence Livermore National Laboratory
Livermore, CA 94550 USA
E-mail: boley@llnl.gov
Phone: (925) 423-7365; Fax: (925) 423-5517

ABSTRACT

We have developed models to simulate experiments involving laser illumination of a knife edge in the Optical Sciences Laboratory (OSL) at LLNL, and plasma formation and pinhole closure in Beamlet.

In the OSL experiments, conducted by D. Milam, a 1.053 μm pulse of duration from 5 to 20 ns illuminated a thin blade from the side, with peak edge intensities ranging from 40 to 1000 GW/cm^2. The parameters and materials (stainless steel, molybdenum, and tantalum) were representative of pinhole experiments on the transport spatial filter of Beamlet. A probe beam grazed the knife edge at a small angle to the main beam, and streaked interferometry yielded fringes as functions of distance above the blade and time.

To calculate the development of the plasma ablated from the blade, we employed the two-dimensional radiation hydrodynamics code LASNEX. According to calculations, the peak electron temperature ranged from 50 to 150 eV, depending on the edge intensity and material. From the electron density distribution, we calculated the phases of the probe beam by utilizing the code HOLOX, which was developed by M. K. Prasad. At each time, the phase was found to decrease nearly exponentially with distance from the blade, indicating that the line-integrated electron density profile (sufficiently below the critical density) also fell off exponentially. The experimental phases behaved similarly. The speeds of the first few wave contours were fairly constant during the pulse, decreasing with atomic weight. The calculated phase profile nearly always exceeded the measured phase, by a typical factor of 2-4, with the dominant error likely due to the lack of three dimensions in LASNEX. In both calculation and experiment, however, the phases satisfied simple fits in distance and time. These fits suggested a way to adjust the LASNEX electron densities to experiment.

We applied these knife-edge simulations to model 4-leaf pinholes on Beamlet. LASNEX-generated plasmas, suitably calibrated, were attached separately to each blade. Speckle in the intensity was taken into account in an approximate way, and allowance was made for the decrease in edge loading away from the center of the blade. The resulting electron density within the pinhole region was converted to an aberration distribution. We then employed a propagation code to calculate the evolution of the wavefront through the entire spatial filter. We present results for a selection of pinhole sizes and materials.

* This work was performed under the auspices of the U. S. Department of Energy by the Lawrence Livermore National Laboratory, under contract number W-7405-ENG-48.

High-Fluence and High-Power 1.05 μm and 351 nm performance experiments on Beamlet

S.C. Burkhart (LLNL), K.R. Brading (LLNL), P.M. Feru (CEA), M.R. Kozlowski (LLNL), J.E. Murray (LLNL), J.E. Rothenberg (LLNL), B.M. Van Wonterghem, P.J. Wegner (LLNL), T.L. Weiland (LLNL)

University of California
Lawrence Livermore National Laboratory
Livermore, CA 94550 USA
E-mail: burkhart1@llnl.gov
Phone: (510) 423-2061; Fax: (510) 423-5517

ABSTRACT

Beamlet is a single-beamline scientific prototype of the National Ignition Facility (NIF) laser system. In previous papers, Van Wonterghem et.al. documented Beamlet 1.05 μm performance[1] to and beyond NIF design fluences, based upon experiments performed up to October, 1996. Since that time, we have installed and activated a final optics test chamber, (the "Test Mule") for testing prototype NIF optics at high fluences, and reactivated our diagnostic system for characterizing the equivalent target chamber center 351 nm focal spot. This system was extensively used to measure frequency conversion and optics damage using prototypical NIF optics and mechanical assemblies, at cleanliness levels specified for NIF operation. Initial operation of the "Test Mule" involved a wedged lens, but subsequent tests at high-fluence used a more NIF prototypical centered (unwedged) lens. The final frequency conversion experiments tested frequency conversion crystals from the NIF first 4X2 bundle KDP and KD*P boules. Silica optics fabricated for high damage-threshold operation were also tested at fluences relevant to long-term NIF operation.

Pinhole closure experiments at 1.05 μm were performed with round conical pinholes, diamond-shaped conical pinholes, and offset-leaf pinholes for pulseshape and energy at NIF requirements. Pinholes down to 100 μr were tested. New techniques for determining onset of pinhole closure were installed, including a streaked pinhole interferometer and a gated near-field optical imager. A number of experiments on spectrally dispersed beam propagation were performed.

Numerous upgrades on the 1.05 μm part of the laser improved its reliability and safety against the threat of catastrophic lens implosion. These included a remote laser damage inspection system for all vacuum large vacuum barrier optics, a SBS bandwidth fail-safe system, and replacement of all spatial filter lenses with thicker, square, lenses. In addition, we reactivated the 1.05 μm mirror testing station and activated the NIF prototype damage inspection system which was used during 351 nm optics damage experiments. These system upgrades will be discussed along with a summary of experimental results from our campaigns and operations over the past 18 months.

1. B.M. Van Wonterghem et. al., "High fluence 1.05 μm performance tests using 20 ns shaped pulses on the Beamlet prototype laser," 2'nd Annual International Conference on Solid State Lasers for Application to Inertial Confinement Fusion, SPIE 3047, 66-72 (1997).

This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory, under contract number W-7405-ENG-48.

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LONG-LIFETIME, LOW-CONTAMINATION METAL BEAM DUMPS FOR NIF SPATIAL FILTERS

M.A. Norton, C.D. Boley, J.E. Murray, K. Sinz, K. Neeb

University of California
Lawrence Livermore National Laboratory
L-490, P.O. Box 808, L-479
Livermore, CA 94550
(925) 422-5481 / Fax (925) 423-5517

The laser architecture of the NIF beamlines requires small-area beam dumps to safely absorb back reflections and leakage through the PEPC switch. The only location available for these dumps are within the confines of the vacuum spatial filters where the available area is restricted. The fluences these dumps must absorb are very large, beyond the damage threshold of optical materials. Off line tests, modeling results and NOVA shots are used to develop a robust beam dump for NIF.

The requirement to robustly dissipate unwanted laser energy from hundreds to thousands of joules per square centimeter within the vacuum spatial filters led to the investigation of metal as the intercepting surface. Stainless steel was studied in some detail for its suitability in this application. Electropolished stainless, type 304, was utilized in the reported measurements, all of which were made in a vacuum which is representative of that found in spatial filters.

An off-line laser system was used to scan four orders of magnitude in fluence from 1 J/cm^2 to 10 kJ/cm^2, and removal depths were measured as a function of fluence. The removal of stainless steel throughout the irradiance range of 10^8 to 10^{12} W/cm^2 has been measured. The sensitivity to laser repetition rate, angle of incidence and beam area was explored. Calculations which describe evaporation, hydrodynamic expansion, propagation, and absorption in one dimension estimate the ablation depths.

Additionally, the ablated material was collected on an arrangement of glass plates and the angular distribution was inferred from the thickness of the deposits. The data show highly peaked distributions about the surface normal. The intended application imposes the requirement that the absorbing part remain intact for thousands of shots, and that the size and weight should be minimal. The possibility of rupture of the material was investigated computationally and verified experimentally.

These measurements, along with some additional considerations that will be discussed, have allowed the design of a suitable beam dump to be used in this application.

This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory, under contract number W-7405-ENG-48.

МЗ-1

High-power neodymium phosphate glass laser facility "Luch" - prototype of a module of the "Iskra-6" facility.

S.A.Sukharev.

RFNC-VNIIEF, Sarov, Nizhniy Novgorod region, Russia, 607190, pr. Mira 37.
Phone (83130) -4-56-46. Fax: (83130) -5-45-65.
E-mail: Sukharev@otd.13.vniief.ru

Abstract

The results of the development of project of 4 channel Nd phosphate glass laser facility "Luch" are presented. The principle of 4-pass amplification of short pulse with profiled temporary form and pulse duration of $\tau_{0,5} \approx 3\text{-}5$ ns in two amplifying cascades with beam aperture of 20x20 cm^2 is used as the basis of the facility design. The facility includes the system of reference radiation formation SRRF (consists of master oscillator, subsystems forming spectral, temporal and spatial-angular parameters of radiation, and preamplifying system); the adaptive system of laser beam wavefront correction; transport and cavity angular spatial filters; main amplifying cascades placed in four-pass cavity; system of power conditioning, and non-linear frequency converters.

The technical characteristics of the facility main systems have been determined. The optical scheme of the facility arrangement in the existing room have been developed. Methods of radiation pulse profiling with various intensities and prepulse durations have been defined and experimentally tested. The basic principles of adaptive system construction have been determined. The evaluations of frequency conversion of the output radiation to the third harmonic in the KDP (KD*P) crystals for various synchronism schemes have been fulfilled. The requirements to laser beam parameters at the output of SRRF have been worked out. The computation of pulse amplification have been carried out. For input energy per channel of $E_{input} \approx 0{,}2$ J, the output energy of a facility channel will be $E_{\lambda=1053нм} \approx 4$ kJ (value of B-integral does not exceed 1,8). The expected energy after conversion of radiation to the third harmonic will be $E_{\lambda=351нм} \approx 3$ kJ from a channel, with full output energy ≈ 12 kJ at the wavelength $\lambda = 351$ nm.

The "Luch" facility is the prototype of a module of the 128-channel Nd phosphate glass laser facility "Iskra-6", with planning output energy $E_{\lambda=351нм} = 300$ kJ and with pulse duration $\tau_{0,5} \approx 3\text{-}5$ ns.

STATE OF PROGRESS OF HIGH-EFFICIENCY TECHNOLOGY OF KDP TYPE CRYSTAL GROWTH

V.I.Bespalov, V.I.Bredikhin, V.P.Ershov, V.V.Zilberberg

Institute of Applied Physics RAS, 46 Uljanov st., 603600 Nizhny Novgorod, Russia

Phone: 7(831)236-5662
Fax: 7(831)236-3792
E-mail: bredikh@appl.sci-nnov.ru

At present KDP type crystals are the only material fit for fabrication of radiation frequency multiplication elements and Pockels cells for high-power laser systems (NIF, MJ, Iskra-6) and will, evidently, remain such in near future. Therefore, the problem of developing a high-efficiency technology of KDP, DKDP crystal fabrication for optical element blanks of large size and high optical quality is still urgent.

The technology of rapid growth of profiled crystals elaborated in IAP RAS seems to be most promising from this point of view. The basic principles of the technology and its development were reported at previous ICF conferences. Essential results have been achieved recently in the technology elaboration. In particular, new methods of profiling have been developed enabling one to grow single-crystal blanks of practically arbitrary orientation. New crystallization setups were designed and manufactured. Characteristics of the crystals obtained in them are close to the requirements of ICF setups. To increase their optical and mechanichal strength methods of postgrowth crystal processing are employed. The report deals with recent achievements as well as with encountered problems and perspectives of their solution.

Ghost Analysis Visualization Techniques for Complex Systems: Examples From the NIF Final Optics Assembly

James L. Hendrix - AlliedSignal FM&T*,
John Schweyen - BRO Research,
Glenn Beer - Lawrence Livermore National Laboratory,
Jeffrey Rowe - Lawrence Livermore National Laboratory

Corresponding Author: James L. Hendrix
Lawrence Livermore National Laboratory
7000 East Avenue
L-527
Livermore, CA 94550
510-422-7172
510-424-6085
jlhendrix@llnl.gov

Abstract:

The stray light or "ghost" analysis on the National Ignition Facility's (NIF) Final Optics Assembly (FOA) has proved to be the most complex ghost analysis ever attempted. The NIF FOA consists of a bundle of four beam lines and provides the vacuum seal to the target chamber, converts 1ω to 3ω light, focuses the light on the target, separates a fraction of the 3ω beam for energy diagnostics, separates the three wavelengths to diffract unwanted 1ω and 2ω light from the target, provides spatial beam smoothing, and provides a debris barrier between the target chamber and the up stream optics.

The three wavelengths of light and seven optical elements with three diffractive optic surfaces generates three million ghosts through 4th order. There are over 6000 ghost paths that have greater than 1 J/cm^2 at focus. The shear number of ghost paths requires a visualization method that allows overlapping ghosts on optics and mechanical components to be summed and then mapped to the optical and mechanical component surfaces in 3D space.

This paper addresses the following issues of the NIF Final Optics Ghost analysis: 1) materials issues for stray light mitigation, 2) limitations on current software tools (especially in modeling diffractive optics), 3) computer resource limitations affecting automatic coherent raytrace, 4) folding the stray light analysis into the opto-mechanical design process, 5) analysis and visualization tools from simple hand calculations to specialized stray light analysis computer codes, and 6) attempts at visualizing these ghosts using a CAD model and another using a high end data visualization software approach.

*Operated for the United States Department of Energy under Contract No. DE-ACO4-76-DP00613.

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70 Ns-pulse Development of kJ Channel for Nd-glass Laser Systems using SBS – Compressor.

V.S. Sirazetdinov, V.N. Alekseev, A.V. Charukhchev,
V.N. Kotilev, V.I. Liber, V.A. Serebryakov

Research Institute for Complex Testing of Optoelectronic Devices
188537 Sosnovy Bor, Leningrad region, Russia
Phone: (007)812 694 80 04, fax: (07)812 694 80 08, e-mail: svs@sbor.spb.su

Nd-glass laser systems with SBS-compression of radiation are great for the prospects of obtaining a few ns multi-kJ pulses required for ICF [1]. A high energy 50-100 ns' duration pulse is generated in the laser channel which makes it possible to avoid optical damage of the channel components and radiation self-focusing and consequently to ensure obtaining high energy extraction from active medium. Next the long pulse is further compressed to a few ns in the SBS-compressor.

Development of the above system requires solution to several problems, such as:

- efficient compression of kJ pulse without significant energy losses;
- optical isolation of the laser channel from the SBS-compressed pulse;
- suppression of SBS-amplifier self-excitation and obtaining high pulse contrast;
- development of a compact SBS-compression system with non-linear medium interaction area length fitted to the laser pulse duration.

The optical scheme for the kJ laser channel with Faraday-cell-based isolation system has been presented. The results of experimental study for multipass compact SBS-generator-compressor ensuring pulse compression from 70 ns down to a few ns has been described. The SBS-compressor serves as the seeding stage for the next stage of the SBS-compressor-amplifier system.

To choose optimum laser beam configuration in the SBS-compressor tract [2] both pumping pulse energy, its temporal profile and non-linear interaction mode were taken into consideration, which resulted in obtaining a pulse with ≤ 1 ns font and ~2 ns duration (FWHM).

Parameters of the compression system based on multipass SBS-generator and SBS-amplifier which allow to resolve some indicated problems have been described.

The study is done under ISTC No. 108 Project.

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Geometric Arrangement of Laser Beams in Target Area

TAN Jichun, WEI Xiaofeng*, CHENG Zhe,
ZHANG Xiaoming*, ZHONG Qin,
LIU Lirong, SHI Ziquan

Department of Applied Physics
Changsha Institute of Technology
Changsha, 410073, China;

Institute of Nuclear Physics & Chemistry, China
Academy of Engineering Physics *
Chengdu, 610003, China

Abstract

Arrangements of beams in target area are reported, and the design method of geometrical arrangement for locating laser beams around a target chamber is described in this paper.

The ray tracing method is used based on constrained nonlinear programming techniques. The objective function f(x) is the optical length difference between the real path and the design objective path for each beam with the primary constraints g(x) as follows: (1) beams illuminate the capsule with the incident angles required for the physical experiments. (2) all of the beams propagate with equal (or similar) optical length from the laser amplifier to the target center, and without overlapping each other. (3) beam incident to the reflection mirror Mi with the decided angle Bi , for example, value of Bi is less than or equal to 45 degrees for all transport paths, in addition, the number of mirrors used in each path is equal (or approximately equal).

Algorithms for solution of the problems of minimization the optical length difference function f(x), such as the method of searching for optimum point with constraint inequality g(x) contained multi- variables in conditions of the reduced number of freedom, are stated. The symmetry and/or homogeneity of incident beams at target surface, together with the optical properties of mirror's coating, are discussed according to requirements of the indirect- drive experiment and the direct- drive experiment respectively.

In order to choose a suitable upgrade design for our laser fusion facility, several alternative approaches of path's configuration in target area have been compared in terms of optomechanical performance and convenience for adjustment and maintenance. Double-purpose configuration is suggested which takes account of requirements of the indirect-drive and the direct-drive using the same laser bay. 3-D geometric graph has been drawn, in which the 60 Gaussian beams, divided into N groups, are symmetrically distributed at each of the N cone surfaces which share the target center as their common vertex, (in our design examples N=8 for the direct-drive target with a vertical axis of symmetry; and N=6 for the indirect-drive target, the configurations of north- hemisphere and south-hemisphere are symmetrical about the equatorial plane of the chamber).

Keyword: Ray tracing, Indirect drive, Direct drive, Target area, Laser fusion.

CHENG Zhe, < email: zhechen@nudt.edu.cn >
TAN Jichun <email: yjchen@nudt.edu.cn; Tax: 0731- 4518275, P.R.China>
Department of Applied Physics, Changsha Institute of Technology, Changsha, 410073, China;

Yb^{3+} P_2O_5-RO Phosphate Laser Glasses

Lili Hu T.Izumitani, Shixun Dai and Zhonghong Jiang
Shanghai Institute of Optics and Fine Mechanics, Academia Sinica
P.O.Box 800-216, Shanghai, 201800, P.R.China

ABSTRACT

As pointed by Payne & Krupke[1] Yb^{3+} laser material will come into common use in near term. They reported high stimulated emission cross section $\sigma=7.3\times10^{-20}cm^2$ in Yb^{3+}:S-FAP[1]. How about Yb^{3+} glass? By now Zou et al has shown that Yb^{3+} niobia containing phosphate glasses could give σ as high as $1.30\times10^{-20}cm^2$. But the defect of this kind of glass is its high nonlinear refractive index. Based on these facts, we investigated a series of Yb^{3+} P_2O_5-RO glasses (R=MgO, CaO, ZnO, SrO and BaO). The relationship between absorption spectrum and glass component was studied.Pumped by GaAs laser diode(974nm lasing wavelength), their fluorescent spectra and lifetime were measured. The stimulated emission cross section σ of Yb^{3+} phosphate glasses was calculated by Fuchtbauer-Ladenburg equation. It was found that the highest σ in Yb^{3+} P_2O_5-RO glass can be larger than $1.5\times10^{-20}cm^2$. There is a compromising relation between σ and τ. The lifetime usually is larger than 1ms without H_2O removing treatment. In most case, σ increases with the decrease of P_2O_5 content. The effect of oxides of high valency cations on the σ of Yb^{3+} P_2O_5-RO glasses were also investigated.

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Corresponding author: Dr.Lili Hu
Mailing Addres: P.O.Box 800-216 Shanghai, 201800 China
Phone: +86-21-59534890, Fax:+86-21-59528812
Email:zhjiang@fudan.ac.cn

Yb^{3+} Borate Laser Glasses Containing High Valency Cations

T.Izumitani Lili Hu and Shixun Dai
Shanghai Institute of Optics and Fine Mechanics, Academia Sinica,
P.O.Box 800-216, Shanghai 201800, P.R.China

ABSTRACT

As well known, Nd^{3+}-phosphate glasses are used for high power laser for nuclear fusion. But the lifetime of Nd^{3+} glasses is not long enough. Payne and Krupke[1] shown that Yb^{3+} apatite is more suitable for next generation laser material. Zou and Toratani[2] obtained high stimulated emission cross section(σ=$1.3\times10^{-20}cm^2$) in Yb^{3+}:Nb containing phosphate glass. But its nonlinear optical refractive index n_2 was too high. We investigated Yb^{3+} borate laser glass with σ as high as $1.55\times10^{-20}cm^2$, n_2 less than 1.3×10^{-13}esu. Yb^{3+} gives pseudo 4 level laser, therefore Judd-Oflet theory can not be applied to Yb^{3+} glass. We investigated the relationship between absorption spectrum and glass component experimentally and calculated σ with Fuchtbauer-Ladenburg equation. As a result, we found that borate glasses give high integrated absorption than phosphate glass and by introducing high valency cations such as La^{3+}, Ti^{4+}, Nb^{5+} and Ta^{5+} into B_2O_3-BaO and B_2O_3-ZnO glass systems, higher σ was obtained.

The reason why high valency cations cause high σ is due to these ions give higher strengths. We will discuss the relation between β_{min}, minimum fraction of Yb^{3+} ions which must be balanced the gain with ground state absorption at laser wave length, I_{sat}, the pump saturation intensity, I_{min}, the minimum absorped pump intensity, σ and τ.

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Corresponding author: Dr.Lili Hu
Mailing Addres: P.O.Box 800-216, Shanghai, 201800, China
Tel: +86-21-59534890, Fax:+86-21-59529912
Email: zhjiang@fudan.ac.cn

Yb^{3+} P_2O_5-Nb_2O_5-RO phosphate laser glasses

Zhonghong Jiang, Lili Hu, Shixun Dai and T.Izumitani
Shanghai Institute of Optics and Fine Mechanics, Academia Sincia
P.O.Box 800-216, Shanghai, 201800, P.R.China

ABSTRACT

Zou and Toratani shown that Yb^{3+} P_2O_5-Nb_2O_5-RO phosphate laser glass has high stimulated emission cross section[1]. But they didn't give the systemic study on this niobia containing phosphate glass system. The present work is focused on the systemic investigation of spectroscopic properties of Yb^{3+} P_2O_5-Nb_2O_5-RO phosphate glasses. The glass formation region of P_2O_5-Nb_2O_5-RO system was first studied. The effect of combination of different RO (R=Zn, Ca, Sr and Ba) on the thermal stability of glasses was also investigated. The relation between refractive index n_d and glass composition was also depicted. It is found that glass could be formed in $20P_2O_5$-$30Nb_2O_5$-50RO composition in this glass system. The relation between absorption spectrum and glass composition was studied. With GaAs laser idode(974nm lasing wavelength), the fluorescent spectra and lifetime of Yb^{3+} P_2O_5-Nb_2O_5-RO glasses were detected. It is found that the stimulated emission cross section σ, calculated by Fuchtbauer-Ladenburg equation, increases with the decrease of P_2O_5 content in Yb^{3+} P_2O_5-Nb_2O_5-RO glass. The highest σ of $20P_2O_5$-$30Nb_2O_5$-49(ZnO+CaO+SrO+BaO)-$1Yb_2O_3$ is $1.74\times10^{-20}cm^2$. But its n_d is as high as 1.898. The effect of different kinds of RO oxides on the σ and τ was also investigated.

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Corresponding author: Prof.Zhonghong Jiang
Mailing address: P.O.Box 800-216, Shanghai, 201800, P.R.China
Phone: +86-21-59534890, Fax: +86-21-59528812
Email: zhjiang@fudan.ac.cn

Improving the Microwave Bandwidth of Photoconductive Switches Used in the OMEGA Pulse-Shaping System

K. Green, W. Seka, M. D. Skeldon, R. L. Keck, A. V. Okishev, and Roman Sobolewski
LABORATORY FOR LASER ENERGETICS

University of Rochester
250 East River Road
Rochester, NY 14623

ABSTRACT

To create temporally shaped optical pulses from a baseband electrical signal, the OMEGA laser-pulse-shaping system currently requires optically activated silicon switches (OASS).[1] These switches generate and gate electrical pulses at a 5 Hz repetition rate. The advantages of an OASS system over competing alternatives include ease of integration with the existing microstrip pulse-shape design and laser infrastructure, picosecond rise- and fall-times, and requisite electrical baseband coverage to approximately 10 GHz.

An OASS is realized by a short length of silicon material that replaces a segment of the microstrip transmission line electrode. These OASS's serve two purposes on OMEGA's laser-pulse-shaping system. The initial purpose is to generate a nanosecond electrical square pulse with approximately 100-ps edges by a rapid transition from the semiconducting to the conducting state by optical illumination. While the OASS remains in the conducting state, its second purpose is to allow a shaped electrical pulse containing microwave spectral components up to 10 GHz to propagate through it with minimal attenuation and distortion. If the shaped microwave pulse duration is made much shorter than the semiconductor free-carrier recombination time, temporal distortion due to switch conductivity decay will be minimized. For the nanosecond-scale pulse lengths desired by OMEGA, the microsecond free-carrier lifetime of high-purity silicon sufficiently minimizes this decay distortion.

Early experiments[2] revealed the OASS to be the bandwidth-limiting element in the pulse-shaping system. Time-domain reflectometry and spectrum analysis confirmed that the rest of the system had sufficient bandwidth to support 100-ps electrical rise- and

fall-times, therefore to improve the improve the system bandwidth we were required to determine which OASS properties affected the bandwidth. A microwave lumped-element model of the switch was necessary to relate physical properties of the switch to their effect on the bandwidth.

Standard vector network analysis techniques are inadequate for analysis due to the time-varying nature of the OASS. We developed a novel microwave vector time-varying network analysis method for our measurements. This method is uniquely capable of measuring the time-varying impulse response function of the OASS. By measuring the impulse response, we are able to create a microwave circuit model of the switch and, from it optimize the fabrication parameters of an OASS in a predictable manner. Optimizing the OASS will increase the available pulse-shaping bandwidth, or equivalently the rise- and fall-time, provided by OMEGA's shaped optical pulses.

ACKNOWLEDGEMENT

This work was supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under Cooperative Agreement No. DE-FC03-92SF19460 and the University of Rochester. The support of DOE does not constitute an endorsement by DOE of the views expressed in this article. K. Green also acknowledges the support of the Frank Horton Graduate Fellowship Program.

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K. Green
Laboratory for Laser Energetics
University of Rochester
250 East River Rd.
Rochester, NY 14623
Phone: 716-275-3941
Fax: 716-275-5960
email: kgre@lle.rochester.edu

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A SUPERCONDUCTIVE FLASH DIGITIZER FOR LASER DIAGNOSTICS*

S. B. Kaplan, D. Brock, D. Gaidarenko, D. Gupta, W. Li, S. V. Rylov

HYPRES
175 Clearbrook Road
Elmsford, NY, USA
Phone (914) 592-1190 x7814, Fax (914) 347-2239
E-mail steve.kaplan@hypres.com

Recording short single-shot laser pulses at the National Ignition Facility (NIF) or the National Laser Users' Facility requires a digitizer with very wide bandwidth and adequate memory storage. We have successfully designed, fabricated, and tested a 6-bit superconductive flash digitizer using Nb trilayer technology. For the first time, we have used a superconductive device to record transient waveforms, and store the data on chip. The digitizer consists of:

1. a flash analog-to-digital converter (ADC) with an input bandwidth well in excess of 10 Ghz,
2. a set of digital superconductive switches to start and stop data acquisition, and
3. a bank of shift-registers for data storage.

The digitizer can function at sampling rates up to 20 GSa/s, although an advanced design is expected to sample at twice that rate. After high-speed data acquisition has been suspended, a low-speed (5-200 MHz) clock signal is used to read out and transmit the data to a logic analyzer and a computer. The on-chip memory is adequate for storing a full NIF laser pulse when operated at 5 GSa/s. At 20 GSa/s, the digitizer is capable of recording more than 6 ns of data. We have used the flash digitizer to acquire and store multi-GHz sine waves. We have also recorded the details of a short pulse containing both a short rise time (~100 ps) and structure with greater than a 10 GHz instantaneous bandwidth.

* Supported by Small Business Innovation Research grants #DMI-9503344 from the U.S. National Science Foundation, and #DE-FG02-95ER81986 from the U.S. Department of Energy.

Fail-Safe Design for Square Vacuum-Barrier Windows*

Tayyab I. Suratwala, John H. Campbell,
William A. Steele, and Rusty A. Steele

University of California
Lawrence Livermore National Laboratory
P.O. Box 808, L-500
Livermore, California 94551-9900
(510) 422-6497

Abstract

Laser induced damage on the vacuum (tensile) side of fused silica optics can result in catastrophic fracture. In previous work, we measured fracture in round windows and lenses and proposed a "fail-safe" design that would insure fracture into only two parts and thus eliminate the possibility of implosion. In this paper we extend the previous work to include square windows and lenses. These results show (Fig. 1) that the expression describing the fracture area for round lenses works equally well for square ones:

$$A_f = 8.4 \times 10^{-5} \sigma_p{}^2 V_L \quad (1)$$

where A_f is the generated fracture area (cm^2), σ_p is the peak tensile stress (psi), and V_L is the window or lens volume (liters). In addition, the effects of variable aperture size are discussed and we show that the maximum tensile stress needed to generate only a single fracture scales as:

$$\sigma_l = \frac{2.7 MPa \bullet m^{1/2}}{\sqrt{l}} \quad (2)$$

where σ_l is the peak tensile stress (MPa) that will result in only one full diameter fracture and l is the characteristic dimension (e.g. radius) of the window. Comparison of our result (Eq. 2) with recent work reported by others who are also researching the conditions at which only one fracture will propagate in a glass plate show good agreement.

*Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

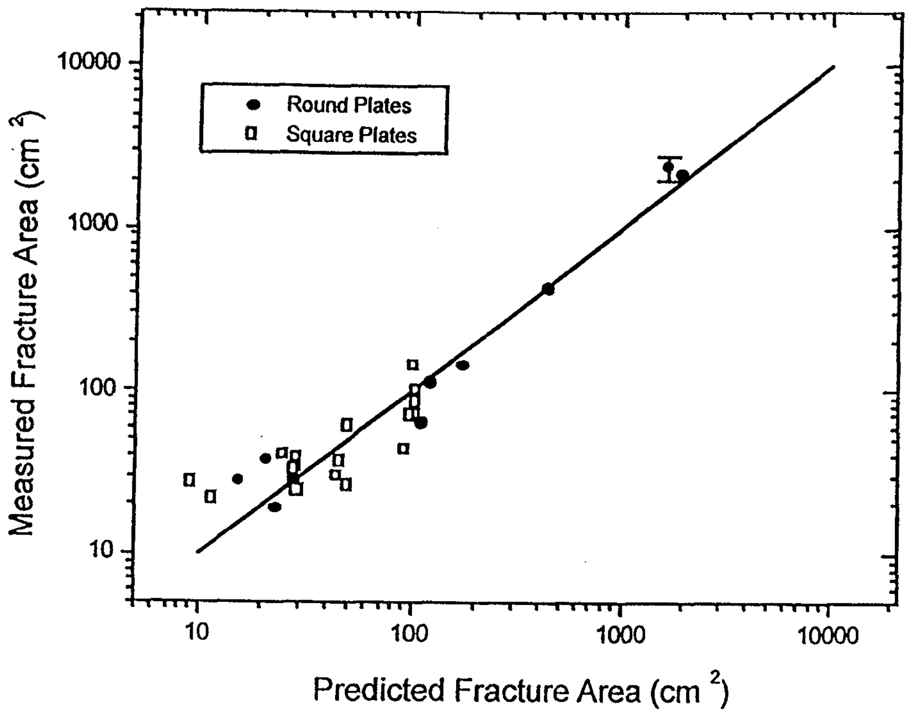

Figure 1. Measured versus predicted (Eq. 1) fracture area for round and square vacuum windows ranging in size from 12 to 80 cm.

Management of Unconverted Light for the National Ignition Facility Target Chamber*

Pam Whitman, Alan Burnham, Mary Norton, Francois Genin,
John Scott, Wilthea Hibbard, Karen Bletzer, Andrew Anderson
Lawrence Livermore National Laboratory, Livermore, CA 94551

The NIF target chamber beam dumps must survive high x-ray laser, ion, and shrapnel exposures without excessive generation of vapors or particulates that will contaminate the final optics debris shields, thereby making the debris shields susceptible to subsequent damage. They also must be compatible with attaining and maintaining the required target chamber vacuum and must not activate significantly under high neutron fluxes. Finally, they must be developed, fabricated, and maintained for a reasonable cost. The primary challenge for the beam dump is to survive up to 20 J/cm^2 of 1μm light and 1 - 2 J/cm^2 of nominally 200 - 350 eV BBT x rays. Additional threats include target shrapnel, and other contamination issues. Designs which have been evaluated include louvered hot-pressed B_4C or stainless steel panels, in some cases covered with film of transparent Teflon, and various combinations of inexpensive low thermal expansion glasses backed by inexpensive absorbing glass.

Louvered designs can recondense a significant amount of ablated material which would otherwise escape into the target chamber. Transparent Teflon was evaluated as an alternative way to capture ablated material. The thin Teflon sheet would need to be replaced after each shot since it exhibits both laser damage and considerable x-ray ablation with each shot. Uncontaminated B_4C, stainless steel, and low thermal expansion glasses have reasonably small x-ray and laser ablation rates, although the glasses begin to fail catastrophically after 100 high fluence shots. Commercially available absorbing glasses require a pre-shield of either Teflon or low thermal expansion glass to prevent serious degradation by the x-ray fluence.

Advantages of the hot-pressed B_4C and stainless steel over glass are their performance against microshrapnel, their relative indifference to contamination, and their ability to be refurbished by aggressive cleaning using CO_2 pellets or glass beads. In addition the expected replacement rate to avoid catastrophic failure makes the glass option more costly. Stainless steel is less expensive, more easily formed into a louver design with high capture efficiency, and otherwise equivalent to B_4C and hence would be preferred as long as it is not shown that debris shield damage from stainless steel is substantially greater for equivalent mass contamination of B_4C and stainless. In this event, the escape of stainless steel could be mitigated by use of a transparent Teflon film. The Teflon film would require increased target chamber pumping and cleaning capability to accommodate the x-ray decomposition products from ablated polymer.

*Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-ENG-48.

Key words: Beam dumps, absorbing glass, laser damage, x-ray ablation

IMPURITY SEGREGATION AND ITS EFFECTS ON THE OPTICAL PROPERTIES OF KH_2PO_4

Ming Yan, Jim J. De Yoreo, Bruce Woods, Mike Staggs, Stavros Demos, RichardTorres, Ian D. Hutcheon, and Natalia P. Zaitseva
Lawrence Livermore National Laboratory, Livermore, CA 94550

Impurities and their interaction with intense laser light are both of fundamental interest in material defect physics and of practical importance in laser fusion applications. The UV damage and optical performance in KDP and KD*P are especially important for the NIF project at LLNL. Here we present the results of investigations into the distribution of impurities in rapidly grown crystals of KDP and their role in optical performance. Impurity levels are measured using optical spectroscopy and mass-spectroscopy. We have classified impurities in the bulk material and the dependence of their concentrations on crystal growth conditions, such as starting solution and growth rate. We have found that Fe is the major species absorbing at 3ω (355 nm) and is the cause of the absorption band at 270 nm. The impurities also cause optical distortion, multiphoton absorption and laser induced heating which leads to spatial inhomogeneity in KDP crystals. The role of impurities in laser induced heating and two photon absorption at 3ω is investigated by time resolved photothermal deflection and Z-scan techniques. The improvement of optical performance using thermal annealing and reduction of impurities in the starting materials will be discussed.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract No. W-7405-ENG-48.

Correspondence Author:
Ming Yan
Lawrence Livermore National Laboratory
L-250
Livermore, CA 94550
Tel: (510) 423-1608
Fax: (510) 422-3361
e-mail: yan1@llnl.gov

Method for Reducing the Effect of Environmental Contamination of Sol-Gel Optical Coatings*

Ian M. Thomas and Alan K. Burnham

ABSTRACT

AR coatings prepared from colloidal suspensions of silica have a large surface area because of their porosity. The surface is quite polar and readily absorbs vapor contamination to the detriment of the optical performance and the laser damage threshold. This effect is particularly bad in "dirty" vacuum systems such as target chambers.

The polar surface is due to residual Si-OH and Si-Ethoxyl groups formed as a result of the method of preparation of the coating suspension. We have now found that these groups can be removed by further treatment of the coating after preparation. This involves two steps, the first being exposure to ammonia and water vapor which hydrolyses the ethoxyl groups to hydroxyl groups with the formation of more Si-OH groups. Some of these react further by self condensation to Si-O-Si linkages. The remaining Si-OH groups are removed in the second step by reaction with hexamethyl-disilazane which converts them to trimethylsilyl groups. The latter are completely non-polar and substantially eliminate vapor absorption.

We have carried out a series of tests involving exposure of treated and untreated coatings to various types of vapor contamination and followed the degree of contamination by the reduction in optical transmission. In all cases, the treated coatings showed a significant reduction in transmission loss.

Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-ENG-48.

NIF Technical Conference Paper
(June 7-12, 1998)

Title: **NIF Deformable Mirror**

Authors: Carlo La Fiandra
NIF Deformable Mirror Program Manager
Senior Staff Engineer
Raytheon Optical Systems, Inc.

Richard A. Zacharias
Lead Engineer
NIF Wavefront Control Systems
University of California
Lawrence Livermore National Laboratory

Mailing Address: Carlo La Fiandra
Raytheon Optical Systems, Inc.
100 Wooster Heights Road
Danbury, CT 06810-7589
(203) 797-5565 (Voice)
(203) 797-5919 (Fax)
cflafiandra@ccgate.hac.com

Preferred
Presentation: Poster

NIF Deformable Mirror

This technical paper describes a new unique form of a Deformable Mirror developed for the NIF beam train. The major technical challenge for this mirror was designing the assembly to operate and survive under the NIF beam lines high energy, high intensity, flash lamp UV pulse. This paper describes the current state of the art, the requirements, the configuration, special features, choice of materials, and fabrication and test details.

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NUMERICAL SIMULATIONS OF A PHASE CORRECTOR PLATE FOR NIF

Wade H. Williams

Lawrence Livermore National Laboratory
P.O. Box 808, L-490 Livermore, CA 94551
Phone (925) 423-1945, Fax (925) 423-1076
E-mail wwilliams@llnl.gov

Simulations are presented of the effect of placing a static phase corrector plate in each NIF beamline to assist the adaptive optic in correcting beam phase aberrations. Results indicate such a plate could significantly improve the focal spot, reducing a 3ω, 80% spot half-angle from 21 to 8 μrad for poorer-quality optics, and 17 to 7 for better optics. Such a plate appears to be within the range of current fabrication technologies. It would have an alignment requirement of ±0.5 mm, if placed in the front end. In NIF operation, the occasional replacement of laser slabs would slowly degrade the beam quality for a fixed corrector plate, with the spot size increasing from 8 to 15 μrad after three new slabs for poorer optics, and 7 to 12 μrad for better optics. The energy fraction clipped on the injection pinhole (±100 μrad) would be <0.5% due to this pre-correction.

* Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

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NIF'S BASIC FOCAL SPOT FOR FLAT IN TIME PULSES*

Wade H. Williams, Richard A. Sacks, Mark A. Henesian,
Steven W. Haan and Janice K. Lawson
Lawrence Livermore National Laboratory
P.O. Box 808, L-490, Livermore, California, U.S.A. 94551
(510) 423-1945 FAX (510) 423-1076
williams34@llnl.gov

ABSTRACT

The characteristics of the focal spot of a NIF beam for flat in time pulses; i.e., its angular power spectrum, will be discussed in the context of the system's optical phase errors and the deformable mirror's (DFM) ability to correct them.

There are several sources of phase errors in the NIF laser system and the largest errors come from the one micron laser. The largest error results from pumping the amplifier and is referred to as the prompt pump induced phase errors. A second source of phase error in the large aperture part of the laser results from the figuring and mounting the optics. Additional phase errors result from the finishing of the optics and these are referred to as PSD phase errors. Another source of phase error results from the intensity dependent phenomeneon of self focusing.

The flowdown to critical system interfaces of the effect of these phase errors on the flat in time focal spot and the DFM's ability to correct them will be discusssed. Certain advanced phase correction schemes can be incorporated into the baseline system if the need arises. These advanced correction schemes and the improvement in the focal spot that they produce will be discussed.

*Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

NIF'S BASIC FOCAL SPOT FOR ICF SHAPED TEMPORAL PULSES*

Wade H. Williams, Richard A. Sacks, Mark A. Henesian,
Steven W. Haan and Janice K. Lawson
Lawrence Livermore National Laboratory
P.O. Box 808, L-490, Livermore, California, U.S.A. 94551
(510) 423-1945 FAX (510) 423-1076
williams34@llnl.gov

ABSTRACT

The characteristics of the focal spot of a NIF beam for ICF shaped temporal pulses; i.e., its angular power spectrum, will be discussed in the context of the system's optical phase errors and the deformable mirror's (DFM) ability to correct them.

There are several sources of phase errors in the NIF laser system and the largest errors come from the one micron laser. The largest error results from pumping the amplifier and is referred to as the prompt pump induced phase error. A second source of phase error in the large aperture part of the laser results from the figuring and mounting the optics. Additional phase errors result from the finishing of the optics and these are referred to as PSD phase errors. Another source of phase error results from the intensity dependent phenomeneon of self focusing.

The flowdown to critical system interfaces of the effect of these phase errors on ICF shaped temporal pulses focal spot and the DFM's ability to correct them will be discusssed. Certain advanced phase correction schemes can be incorporated into the baseline system if the need arises. These advanced correction schemes and the improvement in the focal spot that they produce will be discussed.

*Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

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ASSESSMENT OF THE DAMAGE THREAT FOR THE TWO BASELINE ICF SHAPED TEMPORAL PULSES*

Michael D. Feit, Wade H. Williams, C. Clay Widmayer, Richard A. Sacks, Paul A. Renard, and Mark A. Henesian
Lawrence Livermore National Laboratory
P.O. Box 808, L-4390, Livermore, California, U.S.A. 94551
(510) 422-4128 FAX (510) 422-5537
feit1@llnl.gov

ABSTRACT

The high power and high energy temporally shaped ICF pulses pose a damage threat to the optics in the NIF laser system. In particular the phase noise put on the beam by optical finishing errors and defects in the optics grows as a result of the phenomenon to self-focusing. The control of the damage threat posed by beam break-up and "hot" holographic image formation will be discussed.

The flowdown of the damage threat to the key system components will be presented.

*Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

Optical Design of the NIF Main Laser and Switchyard/Target Area Beam Transport Systems

John L. Miller, R. Edward English - Lawrence Livermore National Laboratory, Ronald J. Korniski - Optics 1, J. Michael Rodgers - Optical Research Associates

Corresponding Author: John L. Miller
Lawrence Livermore National Laboratory
P.O. Box 808, M/S L-527
Livermore, CA 94550
510-423-0311
510-424-6085
jlmiller@llnl.gov

Abstract:

This paper will describe optical design requirements, the design configuration, and design performance for the NIF main laser and switchyard/target area beam transport systems. The main laser layout was driven by beam imaging requirements, lens ghost stay-out zones, and packing constraints associated the organization of beams into 2 wide by 4 high bundles and the building size.

The beam paths through the system are determined by the layout, the spatial filter pinhole arrangement, and constraints applied by the automatic alignment system. Optics sizes were determined from a clear aperture budget that is based on a paraxial model for the laser that incorporates the alignment constraints and has allocations for alignment and installation tolerances. The limiting apertures of the system are 400 mm square amplifier and final optics mechanical hard apertures. The optics sizes will be presented.

Comprehensive optical ray trace models of individual beamlines for the main laser have been developed. The models explicitly include the optical effects of the alignment system references and control degrees of freedom. The spatial filter lenses are nominally symmetric bi-convex. Spherical aberration is corrected in each lens. The transport spatial filter lenses are tilted by 2.8° to reduce the length of ghost stay-out zones; these lenses utilize bilaterally-symmetric aspherical surfaces to correct the tilt aberrations. Design wavefront and pupil imaging performance and tolerance sensitivities will be presented.

The switchyard/target area beam transport system is a complex array of 832 mirrors that maps the rectangular arrangement of beams in the laser bays to the spherical arrangement at the target chamber. The mirrors must transport the 1053 nm beam to the final optics assembly and transport a 351 nm diagnostic reflection back to the transport spatial filter.

Ray trace models have been developed for all beamlines. The mirror sizes are set using design rules that consider the design alignment degrees of freedom and alignment references and that include allocations for beam motion due to target focus position, and alignment and installation tolerances. The mirror configuration and range of mirror sizes will be presented.

The NIF optical design is being documented in configuration and element drawings; examples will be shown.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

NIF Main Laser Stray Light Analysis and Control

John L. Miller, R. Edward English - Lawrence Livermore National Laboratory,
John Schweyen, Gary Peterson - Breault Research Organization

Corresponding Author: John L. Miller
Lawrence Livermore National Laboratory
P.O. Box 808, M/S L-527
Livermore, CA 94550
510-423-0311
510-424-6085
jlmiller@llnl.gov

Abstract:

Stray light considerations affect the NIF main laser layout, the spatial filter lens design, and the design of and choice of materials for features in beam tubes and spatial filter vessels. This paper will describe the analysis methodology used, give examples of design choices based on stray light concerns, and describe the design documentation.

The primary analysis tool is a comprehensive ASAP (®) model; this non-sequential ray trace model includes all optical surfaces as well as beam tube, optic mount, and spatial filter pinhole baffle features. This is supplemented by additional sequential ray trace and diffraction propagation analysis. Ghosts from nominally transmitting surfaces are modeled through fourth order. Particular attention is given to "pencil beams", which are caused by light from spatial filter lens ghosts that is accepted by pinholes.

Examples of areas where the layout was affected by ghost foci are: the vicinity of the Pockels cell, where there are several second and higher order ghost foci caused by a cavity spatial filter lens (SF2) and other surfaces; and the proximity of the power amplifier to a transport spatial filter lens (SF3), which caused this lens to be tilted. Examples of stray light affecting beam tube features are: baffles in the beam tube between the main amplifier and the adjacent cavity spatial filter lens (SF1); absorbers in the cavity spatial filter for Pockels cell ghosts; and beam dumps in the spatial filters for Pockels cell/polarizer leakage and target back reflections. The choice of materials for structural elements in the "periscope" area (near the polarizer and elbow mirror) is also complicated by compatibility with stray light in this area.

Main laser stray light control will be documented by: ghost stay-out zones on configuration drawings, ghost catalogs, and supporting technical memos. Examples will be given.

The locations of significant ghost foci and stray light fluences on optics and structures will be presented. In addition. locations of baffles and absorbers and considerations for the choice of their materials will be discussed.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

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TH3A-1

THE NATIONAL IGNITION FACILITY (NIF) WAVEFRONT CONTROL SYSTEM

Richard Zacharias, Erlan Bliss, Mark Feldman, Andrew Grey, Mark Henesian, Jeff Koch, Rick Sacks, Thad Salmon, John Toeppen, Lewis Van Atta, Paul Wegner, Wade Williams, and Scott Winters
Lawrence Livermore National Laboratory
7000 East Ave., Livermore, CA 94550

Carlo LaFiandra
Raytheon Optical Systems Inc.
100 Wooster Heights Road, Danbury, CT 06810-7589

Don Bruns
ThermoTrex Corporation
10455 Pacific Center Court, San Diego, CA 92121-4339

The NIF laser system focal spot minimum size is limited by wavefront aberrations in the system. For most of its missions, NIF requires a wavefront control system to produce a small enough focal spot. Sources of aberrations that must be corrected include prompt pump-induced distortions in the laser slabs, thermal distortions in the laser slabs from previous shots, manufacturing figure errors in the optics, beam off-axis effects, gas density variations, and gravity, mounting, and coating-induced optic distortions.

The NIF wavefront control system consists of five subsystems: 1) a deformable mirror, 2) a wavefront sensor, 3) a computer controller, 4) a wavefront reference system, and 5) a system of fast actuators to allow the wavefront control system to operate to within one second of the laser shot. The system includes the capability for *in situ* calibrations and operates in closed loop prior to the shot. Shot wavefront data is recorded.

This paper describes the function, realization, and performance of each wavefront control subsystem. Subsystem performance will be characterized by computer models and by test results. The focal spot improvement in the NIF laser system effected by the wavefront control system will be characterized through computer models.

* Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

Pinhole "Closure" in Spatial Filters of Large-Scale ICF Facilities

R. G. Bikmatov, I. N. Burdonskii, V. M. Chernyak, A. Yu. Goltsov, V. N. Kondrashov, N. G. Kovalskii, V. N. Kuznetsov, J. R. Murray (*) M. I. Pergament, V. Ì. Petryakov, R. V. Smirnov, V .I. Sokolov, E. V. Zhuzhukalo, A. V. Fedorov, S. N. Koptyaev

Troitsk Institute for Innovation & Fusion Researches, Troitsk, Moscow Reg.
142092 Russia,
Phone 7-095-334-0530, Fax 7-095-334-5776, E-mail goltsov@fly.triniti.troitsk.ru
(*) Lawrence Livermore National Laboratory, Livermore, CA 94550 USA,
Phone 1- 510-422-5481, Fax 1-510- 510-422-7748, E-mail murray4@llnl.gov

Pinhole plasma effects on parameters of the laser beam passing through the spatial filter pinhole in conditions of interest for large scale ICF laser facilities were investigated. Modeling of the physical processes (mostly refraction) responsible for pinhole "closure" was carried out on the moderate-scale laser facility at TRINITI. The experiments were conducted with the heating beam energy up to 40 J in ~15 ns (FWHM) pulses (λ = 1.054 µm). Al, Fe, and Ta pinholes were investigated. The diagnostic approach was chosen based on probing the pinhole region with frequency doubled short (3 ns) laser beam propagating along the spatial filter axis. To study the ablative-plasma dynamics the shadowgraphy and interferometry were used. Also measured were the parameters of transmitted probing beam in the near-field and far-field. It was shown that although the interferometric method was the most informative for investigation of pinhole plasma dynamics but the near field and far field intensity distribution measurements of the transmitted light was simpler, more informative, and reliable for estimation of a spatial filter performance. The rate of pinhole "closure" is found to decrease with the increase in the atomic number of pinhole material. The rate of pinhole closure ranges from ~$5*10^6$ cm/s for aluminum pinhole down to ~$2*10^6$ cm/s for tantalum pinhole in experiments with power density at the pinhole edge of ~$2x10^{10}$W/cm^2. For aluminum and steel pinholes the parameters of the transmitted probing beam deteriorate to unacceptable level for ~15 – 20 ns after the irradiation start. After that time the quality of the transmitted beam in the near field can change dramatically. Pilot experiments with aluminum pinhole of several simple designs do not reveal any advantageous geometry as compared to the ordinary pinhole drilled in thin plate. The effect of transmitted laser light absorption was estimated to be negligible all over the pinhole area except a very narrow region near the pinhole edge. But the energy losses due to refraction and following limitation by output lens aperture could be significant In the same experimental conditions the pinholes of tantalum exhibits quite acceptable performance till the end of the irradiation process (~30 ns). Fast plasma jets converging to the pinhole axis with velocities up to ~10^7 cm/s and significantly deteriorating transmitted probing beam quality are observed.

Smoothing of Far Field Intensity Distribution under Laser Bem Interaction with Pre-formed Plasma

A. Yu. Goltsov, V. N. Kuznetsov, M. M. Pergament Jr., V .I. Sokolov, A. V. Fedorov

Troitsk Institute for Innovation & Fusion Researches, Troitsk, Moscow Reg.
142092 Russia,
Phone 7-095-334-0686, Fax 7-095-334-5776, E-mail pergam@fly.triniti.troitsk.ru

Among numerous techniques of far field intensity distribution smoothing (SSD, ISI, RPP, HF beam deflection by Wiggler system and so on) the method based on the laser beam interaction with the pre-formed plasma is undeservedly forgotten. Meanwhile, both the efficient intensity distribution smoothing and possibility of laser beam amplification after interaction with plasma was demonstrated experimentally [1,2]. The main reason why this approach was not used in practice originates from the fact that the beam smoothing took place in interaction with the plasma produced by the beam itself. However, the situation can be significantly improved if a special individual beam produces the plasma with parameters required for the subsequent smoothing of any laser beam. In our experiments the Nd: glass laser system generated two beams: the first one (up to 40 J at =1.054 m in 15 ns) for plasma production and the second beam (up to 3 J at =.53 m in 3 ns) for investigation of the smoothing process. Interferometry and shadowgraphy were used to study the plasma dynamics. The smoothing process was studied by registration the near- and far-field intensity distributions of probing beam before and after beam-plasma interaction. The spectral width of laser radiation after interaction with plasma was recorded as well. Smoothing capabilities of both the reflection from plasma mirror and the propagation through thin plasma layer with near critical density were studied. The obtained experimental results show that in the both cases efficient intensity distribution smoothing on the irradiated target can be realized.

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Active Fresnel Rhomb Zig-Zag Slab Amplifier - design and test

R.G. Bikmatov, V.M. Chernyak, J.T. Hant (*), L.P. Ignat'ev, V.G. Kuznetsov, K.R. Manes(*), M.I. Pergament, R.V. Smirnov, V.I. Sokolov

Troitsk Institute for Innovation & Fusion Researches, Troitsk, Moscow Reg. 142092 Russia, Phone 7-095-334-0686, Fax 7-095-334-5776, E-mail chernyak@fly.triniti.troitsk.ru
(*) Lawrence Livermore National Laboratory, Livermore, CA 94550 USA, Phone 1-510-422-6228, Fax 1-510-423-6506, E-mail manes1@popsiele llnl.gov

It is well-known that Nd:glass large-aperture slab amplifier with zigzag geometry of laser beam propagation is very attractive as a component for different laser systems. The advantages of such kind of amplifiers are: high pump efficiency, cooling convenience, faint thermo-optical distortion influence, potential for high repetition rate, and possibility to operate at both beam polarizations that propagate through the active element. In addition it allows to join in one unit both large-aperture amplifier and large-aperture polarization component if active element is formed as Fresnel rhomb. This design has been described in our previous reports [1,2], this report summarizes all our results. Laser amplifier had active element 4.5x40x43cm^3 in dimensions, six- bounce geometry of beam pass, pump cavity with transverse lamp orientation, and diffuse reflectors. Incident angle is chosen so that each pair of bounces corresponds to Fresnel rhomb conditions. Among different applications this amplifier could be installed in a multi-channel laser system instead of a number of rod amplifiers so that the amplifier aperture is divided to a number of sub-apertures with the equal output energy of beams. To realize all described above advantages it was necessary to provide:

- gain non-uniformity over operating part of aperture less than +/- 2.5%);
- depolarization distortion over operating part of aperture less than 0.1%.

We carried out simulation of gain uniformity taking into account modulation of active element illumination with transverse oriented flashlamps and depolarization effects caused by residual birefringence, internal (weight) and external mechanical loading, and thermo-optical distortion.

Tests showed that the gain is equal to 8 per single pass at 77 kJ of pumping, and its non-uniformity over about half of amplifier aperture is less than +/-2.5%.

We found that variation of depolarization distortion along small size of the active element is very small. Main contribution in depolarization along of 40 cm - size is determined by two effects: 1) non-uniformity pump illumination, and 2) difference in properties between active medium and cladding material and kinds of their heating. The depolarization effect near active medium - cladding boundary achieves up to 1%. Nevertheless the depolarization distortion over operating area of aperture is less than 0.1%.

Special optical component (loaded glass plate) can be used as a compensator to decrease these distortions.

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LMJ CLADDING Industrialisation

C. Remontet, JM. Bouchut, V. Licchesi*, J. Duchesne**

Angenieux S.A.
F-42570 Saint-Heand, France
Phone : (33) 477.90.78.00 - Fax : (33) 477.90.78.05 - email : angenieux@calva.net

*GIAT Industries
3 rue Javelin Pagnon - F-42000 Saint-Etienne, France

** CEA
Centre d'études de Limeil-Valenton - F-94195 Villeneuve Saint-Georges cedex

ANGENIEUX/GIAT Industries consortium agreement (GME) has been selected by CEA to industrialize the cladding process on amplier slabs used on LIL and MEGAJOULE lasers. Each amplifier slab is clad with Cu-doped glass to absorb 1 053 nm parasitic ASE light, and avoid gain depletion.

Our project started on January 1997. A lot of works have been performed in various fields of activities as cladding cement characterization, definition of an optical bench to detect bonding defects, or grinding and polishing of large amplifier slabs made of Nd-doped glass (450x800x40 mm^3).

In the first part of the poster, main characterizations on cements are shown and measurement results are summarized. We also recall the major importance of refractive index matching between cement and laser glass, and associated measurements are depicted. Others important cement parameters are described among which vitreous transition temperature, viscosity and spectrophotometric measurements. These values are compared with other laboratories results.

This is followed by the definition of optical bench dedicated to check cement defects and that we will industrialize. The control process on cladding defects is described and results on cement samples are discussed. The bench critical parameters are commented.

The last part of the poster is dedicated to the machining and polishing trials performed on large slabs of Nd-doped glass. Main results are summarized, and specific behaviours are discussed.

BEAM POSITION ERROR BUDGET DEVELOPED FOR NIF

Stanley C. Sommer, NIF System Integration - Engineering Analysis
Erlan S. Bliss, Systems Control System Engineer
Lawrence Livermore National Laboratory
P.O. Box 808, L-495, Livermore, California, U.S.A. 94551
(510) 422-6844 FAX (510) 422-4667
sommer1@llnl.gov

ABSTRACT

Major scientific goals of the 192-laser beam National Ignition Facility (NIF), which is being built at the Lawrence Livermore National Laboratory (LLNL), are to "ignite" small fusion targets and to conduct high energy-density physics experiments for evaluating the use of fusion as a viable power source and for nuclear stockpile stewardship activities. To achieve these goals, the position and direction of all 192 beams must be sufficiently stable to allow their accurate alignment through the laser to the target and to maintain that alignment until the shot is complete. This presentation will provide an overview of the NIF stability requirements, review the development of stability allocations, and discuss efforts to evaluate the stability response of NIF optical support structures.

NIF stability allocations are primarily developed from the requirement that the deviation in the position of all the beams on target shall not exceed 50 microns. The major contributors to the beam position on target are the accuracy of the alignment process and the stability of the laser system before and during a shot. System stability also affects the repeatability of frequency conversion efficiency and the successful operation of narrow field-of-view diagnostics.

All components that are involved in beam alignment or are capable of moving a beam on the target must meet the requirements of the NIF stability budget, and allocations in this budget must take account of three major aspects of the problem. First, there are multiple input sources that can cause structural drift, such as ambient vibration, acoustical excitation, wind fluctuations, flow-induced vibrations, and thermal transients. In addition, there are thousands of structural elements that can transmit or amplify the input perturbations if their design is not optimized. Finally, many of the optics that the structures support are mirrors or lenses whose motion will influence beam propagation. We will present a summary of stability budget values.

NIF optical components are supported in the two laser bays primarily by hybrid support structures of reinforced concrete pedestals and steel frame or vessels and in the switchyards by large steel space frames connected to the corners and cylinder of the reinforced concrete switchyard/target area building. Inside the target area are the target chamber and floors that also support optical components and diagnostic equipment. With analytical models of the support structures and excitation sources defined by power spectral density (PSD) spectra or other appropriate techniques, dynamic analyses have been used to evaluate and demonstrate the stability of the NIF optical components. From the results obtained to date, we expect NIF to meet its stability requirements.

Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

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FORMATION OF TEFLON AF POLYMER THIN FILMS AS OPTICAL COATINGS FOR USE IN LASERS

N. Bazin,* J.E. Andrew, H.A. McInnes, K. Porter, A. Morris

AWE plc Aldermaston, Reading, Berkshire, UK. RG7 4PR

Teflon AF 1600™ and 2400™ for Dupont have been used to make thin film coatings with excellent AR properties. Spin, dip, and meniscus, coating techniques have all successfully formed single layer AR coatings. Multi-dipping of the Teflon AF polymer revealed a close linear relationship between the number of dips and total thickness of the Teflon film suggesting a good adherence between layers of Teflon when a compatible solvent is used. Hexafluorobenzene used as a co-solvent allows good control of the coating thickness by dilution enabling the dipping or spinning rate to remain at their optimum values. Attempts to form high index sols in compatible solvents with Teflon are discussed.

Laser induced damage threshold (LIDT) results at 1ω and 3ω of the single layer AR coatings are reported and compared to available published data. X-ray damage (as a function of fluence and spectrum) and target by-product damage of the Teflon coatings is also discussed.

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TU 2B-3

Characterisation of Sol-Gel multilayer films for applications in lasers using UV-Vis spectroscopy and dynamic SIMS/ AES/

N. Bazin,* J.E. Andrew, H.A. McInnes, K. Porter, A. Morris

AWE plc Aldermaston, Reading, Berkshire, UK. RG7 4PR

Multilayer Sol-gel thin films have been developed for the application on high power glass lasers. The macroscopic properties such as optical reflectivity /transmission and laser damage threshold for various materials, deposition methods and number of layers have been assessed.

In addition, several techniques have been employed to study the microscopic behaviour of the individual layers and interfaces. An overview of the three different depth profiling techniques is presented. Test have been carried out on silicon wafers as well as fused silica substrates. Fused silica substrate yielded the best quality coatings. Depth profiling results from DSIMS, AES, and XPS are contrasted. The results of these thin film analytical techniques are compared to Dynamic light scattering measurements of the sol particles of both the colloidal low index silica and the high index polymeric zirconia.

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W4B-4

A COMBINED PHASE, NEAR FIELD AND FAR FIELD DIAGNOSTIC FOR LARGE APERTURE LASER SYSTEMS

A R Barnes, I C Smith

AWE plc, Aldermaston, Reading, Berks, UK, RG 7 4 PR

A method is described for extracting phase, near field and far field information from an interferogram of a laser system image plane, generated by a self-referencing, radial shear interferometer. It is shown that the interferogram may be used as an intensity mask of a coherent beam which is numerically propagated to the far field where the image plane beam, its complex conjugate and the reference beam can be separated. The near field and phase may then be extracted from the wavefunction obtained by back propagating to the near field. The practical application of this method and its limitations are discussed and compared with images from conventional far field and near field diagnostics on the HELEN 2 TW glass laser system.

The Cross-Phase Modulation between Two Intense Orthogonally Polarized Laser Beams Co-Propagating through a Kerr-like Medium

J. A. Marozas

ROCHESTER THEORY CENTER FOR OPTICAL SCIENCE AND ENGINEERING
and
LABORATORY FOR LASER ENERGETICS
University of Rochester
Rochester, NY 14627

Propagation of two orthogonally polarized beams with an initial pseudorandom phase perturbation within a Kerr-like medium is modeled. Scalar diffraction and nonlinear cross-phase modulation are treated using a split-step method which can yield catastrophic self-focusing effects. It is found that catastrophic self-focusing on the OMEGA laser system may be eluded when the beams are propagated through 12 m of air if the intensity and the initial pseudorandom phase perturbation meet certain criteria. The uniformity requirements for inertial confinement fusion (ICF) on the OMEGA laser system have provided the impetus to include an additional method known as polarization smoothing that decreases the instantaneous speckle nonuniformity. If a wedge of KDP [referred to as a distributed polarization rotator (DPR)] is placed in the beam path with the *o* and *e* axes at 45° to the polarization vector, the birefringence causes two orthogonal linearly polarized beams to emerge that diverge as they co-propagate. When these beams reach the target plane, their offset will effectively smooth out some of the laser speckle pattern. In any plane perpendicular to the beam path the two beams interfere, producing a polarization state that cycles from linear to circular with every elliptical state in between, in a manner similar to a Babinet compensator. The difference between the nonlinear refractive indices for linear and circular polarization states can induce a sinusoidal amplitude perturbation across the beam due to the nonlinear effect of cross-phase modulation. If the beam is intense enough and/or the nonlinear susceptibility constants are large enough, the induced phase perturbation can lead to self-focusing and catastrophic filament collapse. If diamond-turned KDP wedges are used, milling marks on the surface introduce an initial pseudorandom phase perturbation that further complicates the potential self-focusing problem by seeding the nonlinear cross-phase-modulation effect. A significant amplitude ripple may be imposed on the beam front when the frequency of the milling marks is of the order of the polarization cycle.

This research was supported by NSF Grant PHY94-15583. In addition, this work was partially supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under Cooperative Agreement No. DE-FC03-92SF19460, the University of Rochester, and the New York State Energy Research and Development Authority. The support of DOE does not constitute an endorsement by DOE of the views expressed in this article.

J. A. Marozas
Rochester Theory Center for Optical Science and Engineering
and
Laboratory for Laser Energetics
University of Rochester
Rochester, NY 14627
Tel: (716) 275-5772
Fax: (716) 275-5960
email: jimijam@lle.rochester.edu

Preferred Presentation: Oral

Optimisation of the alignment sensitivity and energy stability of the NIF regenerative amplifier cavity.

N. W. Hopps[2], R. B. Wilcox[1], M. R. Hermann[1],
M. D. Martinez[1], E. H. Padilla[1], J. K. Crane[1].

[1] Lawrence Livermore National Laboratory,
PO Box 808, Livermore, California, 94551

[2] Atomic Weapons Establishment,
Aldermaston, Reading, RG7 4PR.
United Kingdom.

ABSTRACT

The work to improve the energy stability of the regenerative amplifier ("regen") for the National Ignition Facility is described. This includes a fast feed-forward system, designed to regulate the output energy of the regen by monitoring how quickly a pulse builds up over many round trips. Shot-to-shot energy fluctuations of all elements prior to (and including) the regen may be compensated for in this way, at the expense of a loss of approximately 50%. Also included is a detailed study into the alignment sensitivity of the regen cavity, with the goal of quantifying the effect of misalignment on the output energy. This is done by calculating the displacement of the eigenmode by augmenting the cavity ABCD matrix with the misalignment matrix elements, E, F. In this way, cavity misalignment issues due to thermal loading of the gain medium are investigated. Alternative cavity designs, which reduce the alignment sensitivity, and therefore the energy drift over periods of continuous operation, are presented. Such cavity designs are especially important shortly after system start-up, when the regen has not yet reached thermal equilibrium. Alterations to the amplifier head design, in order to reduce the pointing error induced by thermal effects, are also described.

Correspondence address:
Nick Hopps
Lawrence Livermore National Laboratory, L-483
7000 East Avenue,
Livermore, CA 94551
Tel: 510-423 2817 Fax: 510-422 9554
Email: hopps1@llnl.gov

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W4A-3

EXPERIMENTAL VERIFICATION OF THE DUAL-TRIPLER SCHEME FOR EFFICIENT LARGE-BANDWIDTH FREQUENCY TRIPLING

A. Babushkin, R.S. Craxton, S. Oskoui,* M.J. Guardalben, R.L. Keck, W. Seka

Laboratory for Laser Energetics
University of Rochester
250 East River Road
Rochester, NY 14623-1299
Tel: (716) 275-1684 Fax: (716) 275-5960 E-mail: abab@lle.rochester.edu

*Also Pittsford Mendon High School, Pittsford, NY

Beam-smoothing schemes for laser fusion, such as smoothing by spectral dispersion,[1] require a large bandwidth on the laser beams, which are usually generated as the third harmonic (351 nm) of the Nd:glass laser wavelength. The smoothing rate on target is presently limited by the bandwidth acceptance of the KDP crystals usually used to perform the third-harmonic generation (THG).

It has recently been proposed[2] that broader-bandwidth THG can be achieved by using dual triplers, i.e., two tripler crystals in series. Specific calculations for the OMEGA laser system indicate that the addition of a second tripler to the existing conversion crystals in each beamline can increase the bandwidth acceptance by a factor of three.[3]

We experimentally measured the conversion efficiency for the dual-tripler THG scheme and compare the measured data with theoretical predictions. Excellent agreement between experiment and theory has been demonstrated (see Fig. 1). Experimental results suggest that the predicted 70%-90% conversion of an optimized design[3] for a flat beam can be achieved and that the OMEGA laser can be converted with a threefold increase of bandwidth by the retrofitting of each beam with an additional tripler crystal.

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This work was supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under Cooperative Agreement No. DE-FC03-92SF19460, the University of Rochester, and the New York State Energy Research and Development Authority. The support of DOE does not constitute an endorsement by DOE of the views expressed in this article.

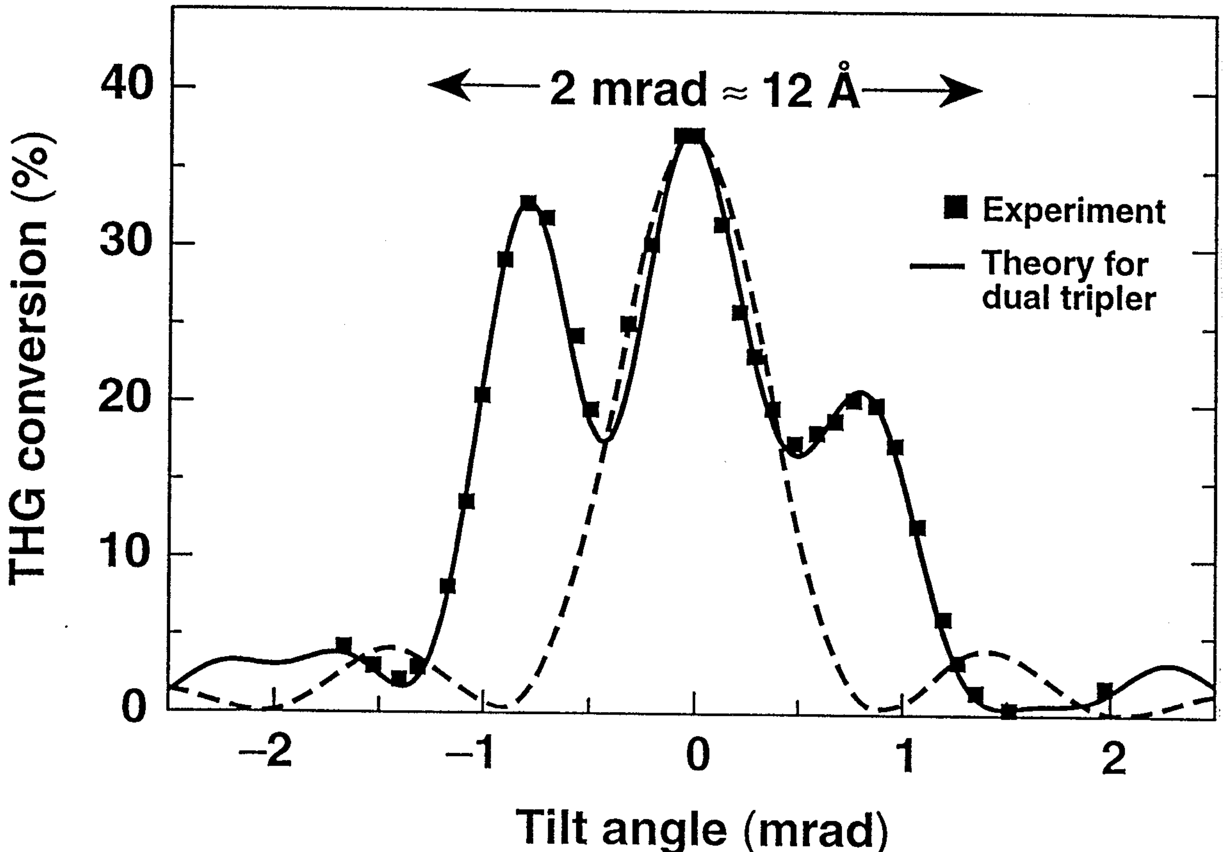

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Fig. 1 Experimentally measured dual-tripler THG turning curve and predictions of the MIXER code, demonstrating a threefold increase in the converted bandwidth in comparison with the standard THG scheme (dashed curve). The 2-mrad full width is equivalent to a 12-Å IR wavelength bandwidth.

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Compact Nd^{3+}-Based Laser System with Gain $G_{SS} \leq 10^{13}$ and 20-J Output Energy

A. Babushkin, J.H. Kelly, C.T. Cotton, M. Labuzeta, M. Miller,
T.A. Stafford, R.G. Roides, and W. Seka

LABORATORY FOR LASER ENERGETICS
University of Rochester
250 East River Road
Rochester, NY 14623-1299

I. Will
MAX BORN INSTITUTE BERLIN, Rudower Chaussee 6, D-12489 Berlin

M.D. Tracy
XEROX, Wilson Center, 800 Phillips Road, Webster, NY 14580

D.L. Brown
KLA-TENCOR, 160 Rio Robles, San Jose, CA 95134

We will present experimental results on a compact laser system capable of amplifying a nanosecond-scale pulse from a few pJ to 20 J. The amplification was performed in two steps. First, a single, bandwidth-limited pulse from a diode-pumped, mode-locked cw Nd:YLF laser was injected into the negative-feedback-controlled regenerative amplifier. At the output of the regenerative amplifier, a single pulse with energy ~0.6 mJ and a duration ~1 ns was switched out from the pulse train generated by the regenerative amplifier and injected into the large aperture ring amplifier (LARA). At the output of LARA the amplified pulse has 20 J of energy, 1-ns temporal duration, and 30-mm flat-top spatial profile (Fig.1). This laser system with an overall gain $\leq 10^{13}$ has a 4-ft X 14-ft footprint. We will discuss this laser system's configuration, characterization, and performance.

This work was supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under Cooperative Agreement No. DE-FC03-92SF19460, the University of Rochester, and the New York State Energy Research and Development Authority. The support of DOE does not constitute an endorsement by DOE of the views expressed in this article.

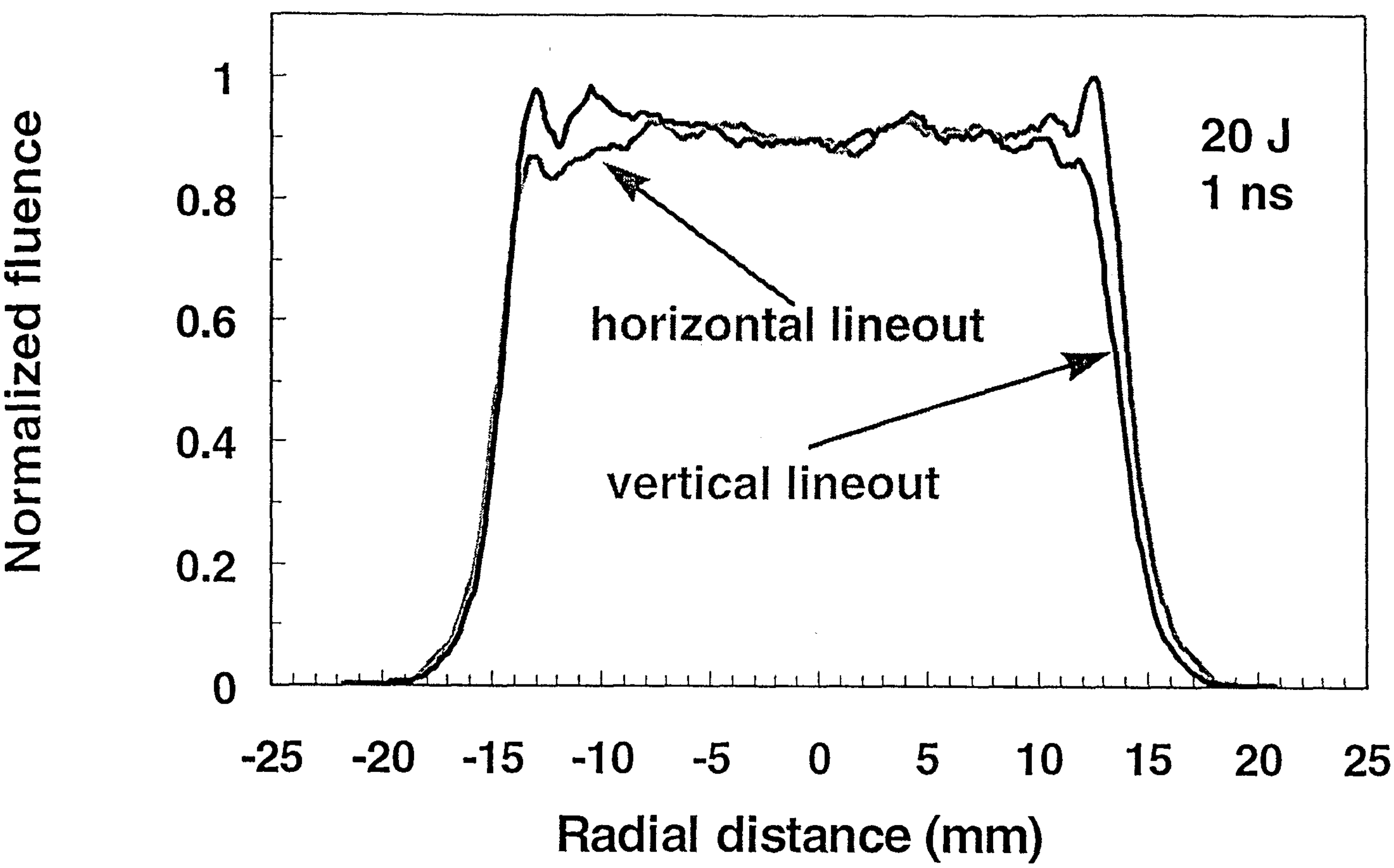

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Fig. 1 Vertical and horizontal profiles for the 1-ns pulse amplified to the 20-J energy. Fluence was normalized to maximum fluence of the image.

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388-B
TU2A-2

REGENERATIVE AMPLIFIER FOR THE OMEGA LASER SYSTEM

A. Babushkin, W. Bittle, M. D. Skeldon, W. Seka

Laboratory For Laser Energetics
University Of Rochester
250 East River Road
Rochester, NY 14623-1299

and

S. A. Letzring

Los Alamos National Laboratory
Los Alamos, NM 87545

The 60-beam OMEGA laser is delivering 30-kJ UV pulses with an arbitrary, predetermined temporal pulse shape envelope. The pulse-shaping system,[1] based on a design developed at the Lawrence Livermore National Laboratory,[2] produces optical pulses of $\leq$10-nJ energy. At the first amplification stage on OMEGA these low-energy pulses are boosted in energy to the submillijoule level in the negative-feedback-controlled regenerative amplifier. The negative-feedback system significantly enhances the performance of the amplification process, allowing to achieve unsurpassed stability (Fig. 1) and reliability for the regenerative amplifiers currently used in the OMEGA laser.

In this contribution we will present requirements, design, and experimental results of a negative-feedback-controlled Nd: YLF regenerative amplifier used on OMEGA. With the present system we have experimentally demonstrated the generation of kilojoule laser pulses with prescribed temporal shape.

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This work was supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under Cooperative Agreement No. DE-FC03-92SF19460, the University of Rochester, and the New York State Energy Research and Development Authority. The support of DOE does not constitute an endorsement by DOE of the views expressed in this article.

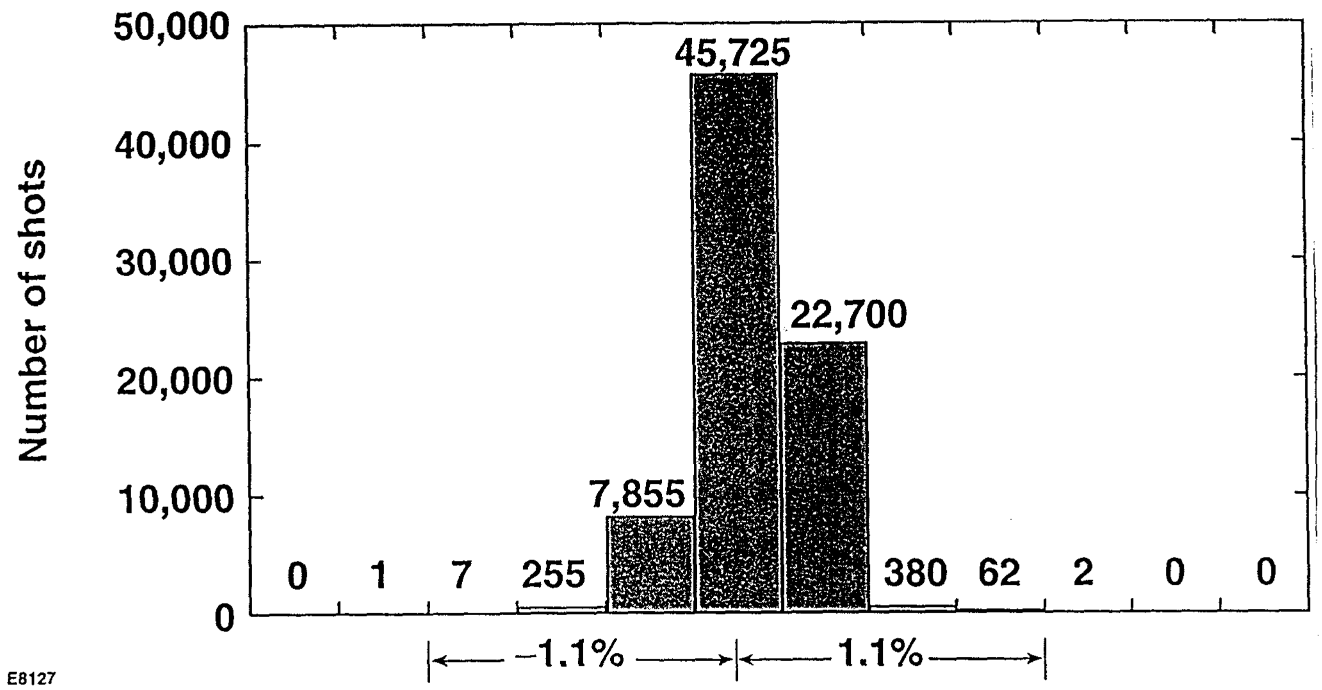

Figure Caption

Fig. 1 Histogram (standard deviation 0.2%) for the single shaped pulse's switchout from the feedback-controlled regenerative amplifier.

Multipurpose, Diode-Pumped Nd:YLF Laser for OMEGA Pulse-Shaping and Diagnostics Applications

Andrey V. Okishev, Mark D. Skeldon, and Wolf Seka
LABORATORY FOR LASER ENERGETICS
University of Rochester
250 East River Rd.
Rochester, NY 14623

ABSTRACT

The OMEGA facility is a 60-beam, 30-kJ (UV) laser system for performing internal confinement fusion (ICF) experiments. One of the main features of the OMEGA laser is an optical-pulse-shaping system capable of producing flexible temporal pulse shapes[1] (Fig. 1). The recently developed diode-pumped Nd:YLF master oscillator[2] is capable of satisfying the basic OMEGA requirements, such as single-frequency, long-pulse, *Q*-switched operation with high amplitude stability. However, some OMEGA operational issues (modulator minimization procedures, bandwidth characterization, increased repetition rate, and temporal diagnostic calibration) have motivated the development of a new diode-pumped multipurpose laser. The new laser is capable of serving as the OMEGA master oscillator (stable, single-frequency, *Q*-switched operation), as a source of stable, single-frequency cw radiation (for modulator characterization and minimization), as well as a source of stable, sinusoidally modulated radiation (for temporal diagnostics calibration).

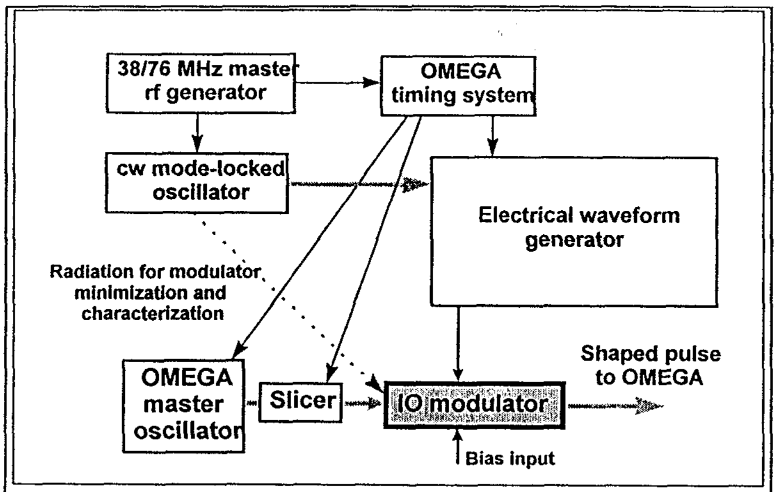

Fig. 1. Block diagram of the OMEGA pulse-shaping system.

The heart of the OMEGA optical-pulse-shaping system is an integrated-optic (IO) modulator. To obtain high-contrast, high-precision, shaped optical pulses, the modulator must be biased to provide zero transmission in the absence of an electrical waveform (modulator minimization procedure). To accomplish this, cw laser radiation from a different laser source than the master oscillator (the cw mode-locked laser) is manually directed to the modulator. This operator intervention is time consuming and unnecessarily stresses fiber-optic connectors and components. This operator intervention is eliminated with a master oscillator that can be easily switched to cw operation.

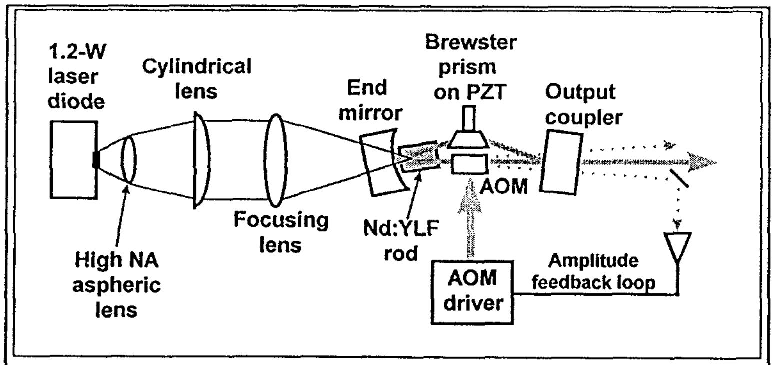

Fig. 2. Block diagram of the multipurpose Nd:YLF laser.

The basic design of the laser (Fig. 2) is similar to the one described earlier.[2]

The pump radiation is collimated and focused into the active element (1053-nm lasing oriented) through the dichroic end mirror. In the cw operation regime [no rf power applied to the acousto-optic modulator (AOM)] the laser generates approximately 260 mW of cw power (in both counterpropagating beams) with an optical-to-optical efficiency >21% at 1053 nm. Unidirectional single-frequency operation is achieved by applying a low (<100-mW) rf power to the AOM. The amplitude feedback loop[2] suppresses relaxation oscillations. By removing the rf power from the AOM we obtain Q-switched pulses (12-to 200-ns pulse width) at a repetition rate up to 10 kHz. Without removing the rf power to the AOM, the laser generates up to 100 mW of single-frequency cw power (optical-to-optical efficiency is ~13%). In both regimes (cw and Q-switched) we measure single-frequency operation over many hours (>11 h) without frequency feedback. The envelope of the pulse taken with a streak camera is extremely smooth indicating high-contrast, single-frequency operation.

By applying controlled feedback to the PZT-mounted prism in the laser cavity, the laser can be forced to operate on two adjacent longitudinal modes of approximately equal amplitudes over many hours. In this case the temporal structure of the pulse is a deeply-modulated sinusoidal signal with the period of ~267 ps. This signal can be particularly useful for OMEGA temporal diagnostics calibration such as streak camera sweep speeds, etc.

In conclusion we have developed a diode-pumped, multipurpose Nd:YLF laser for the OMEGA laser facility that is suitable for our pulse-shaping applications, including modulator minimization and characterization, as well as temporal diagnostics calibration.

ACKNOWLEDGMENT

This work was supported by the U.S. Department of Energy Office of Internal Confinement Fusion under Cooperative Agreement No. DE-FC03-92SF19460 and the University of Rochester. The support of DOE does not constitute an endorsement by DOE of the views expressed in this article.

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A. V. Okishev
Laboratory for Laser Energetics
University of Rochester
250 East River Rd.
Rochester, NY 14623
Telephone: 716-275-5101
Fax: 716-275-5960
e-mail: aoki@lle.rochester.edu

Plans to Achieve 1-THz Bandwidth with Two-Dimensional Smoothing by Spectral Dispersion on OMEGA

J. D. Zuegel, E. M. R. Michaels, S. Skupsky, R. S. Craxton, and J. H. Kelly

LABORATORY FOR LASER ENERGETICS
University of Rochester
250 East River Road
Rochester, NY 14623-1299

S. A. Letzring

LOS ALAMOS NATIONAL LABORATORY
Los Alamos, NM 87545

Two-dimensional smoothing by spectral dispersion (2-D SSD) is an important technique implemented on OMEGA to improve irradiation uniformity on direct-drive inertial confinement fusion targets. The current OMEGA 2-D SSD implementation employs S-band phase modulators operating at approximately 3 GHz and is qualified to propagate nearly 250-GHz bandwidth in the ultraviolet (1.25 × 1.75 Å in the infrared) on target. The long-term goal is to generate over 1-THz ultraviolet bandwidth employing higher-frequency phase modulators along with a dual-tripler frequency-conversion scheme first proposed by LLNL and recently demonstrated at LLE to improve the irradiation smoothing rate.

Important 2-D SSD system design and operating considerations established during the development and operation of the current OMEGA configuration will be presented, including S-band phase modulator performance, 2-D SSD system diagnostics, FM-to-AM conversion mechanisms, and preliminary OMEGA system spatial noise measurements relevant to the maximum angular beam displacement that can be propagated.

By the end of FY98 an enhanced 2-D SSD system will be implemented on OMEGA that is capable of generating over-500-GHz bandwidth in the ultraviolet (3 × 4 Å in the infrared) using the S-band phase modulators as well as accommodating future X-band modulators operating near 10 GHz to achieve the 1-THz-bandwidth goal. Preliminary test results from this enhanced configuration in the off-line SSD testbed, as well as X-band phase modulator designs under investigation, will be presented.

This work was supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under Cooperative Agreement No. DE-FC03-92SF19460, the University of Rochester, and the New York State Energy Research and Development Authority. The support of DOE does not constitute an endorsement by DOE of the views expressed in this article.

J. D. Zuegel
Laboratory for Laser Energetics
University of Rochester
250 East River Road
Rochester, NY 14623-1299
Tel: (716) 275-4425
Fax: (716) 275-5960
email: zuegel@lle.rochester.edu

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W2A-3

APPLICATION OF ADAPTIVE OPTICS FOR CONTROLLING THE NIF LASER PERFORMANCE AND SPOT SIZE

Richard Sacks
Phone (925) 423-2675, Fax (925) 423-6506
E-mail rsacks@llnl.gov

Mark Henesian
Phone (925) 423-1504, Fax (925) 423-6506
E-mail henesian@llnl.gov

University of California
Lawrence Livermore National Laboratory
PO Box 808, L-490 Livermore, CA 94551

The National Ignition Facility (NIF) laser will be a 192-arm multi-pass architecture capable of delivering up to several MJ of UV energy in temporal pulse formats varying from sub-ns square to 20 ns precisely-defined high-contrast shapes. The beam wavefront will be subjected to effects of optics inhomogeneities, figuring errors, mounting distortions, prompt and slow thermal effects from flashlamps, driven and passive air-path turbulence, and gravity-driven deformations. A 39-actuator intra-cavity deformable mirror, controlled by data from a 77-lenslet Hartman sensor will be used to correct these wavefront aberrations and thus to assure that the stringent farfield spot requirements are met.

We have developed numerical models of the nature and magnitude of the expected distortions, of the operation and effectiveness of the adaptive optic system, and of the anticipated effects on beam propagation, component damage, frequency conversion, and target-plane energy distribution. These models have been extensively validated against data from LLNL's Beamlet, and AMPLAB lasers. In this talk we will review the expected beam wavefront aberrations and their potential for adverse effects on the laser performance, describe our model of the corrective system operation, and display our predictions for corrected-beam operation of the NIF laser.

* Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

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MP (repl)

OPTICS DAMAGE INSPECTION FOR THE NIF

Cal Thompson, Carl Knopp, Derek Decker
Lawrence Livermore National Laboratory
7000 East Avenue, L-495, Livermore, CA 94550
Phone: (925) 422-5375 Fax: (925) 422-4667
E-mail: thompson4@llnl.gov

Two optics damage inspection systems will be implemented on NIF, one to inspect optics within the laser and transport sections and the other to inspect the final optics at the target chamber. Both systems use dark-field imaging technology to enhance resolution of defects. Details of each system design will be provided. A functional optics damage inspection system prototype, using dark-field imaging technology, is currently in operation on the Beamlet laser. This system provides us with the opportunity to measure non-ideal optical surfaces expected to be present on NIF. Prototype details and performance will be presented.

*Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

Engineering and modeling progress in building Mercury, a diode-pumped solid-state laser (DPSSL) for ICF applications[1]

C. Orth,[2] R. Beach, C. Bibeau, E. Honea, J. Lawson, C. Marshall,
S. Payne, K. Schaffers, J. Skidmore, S. Sutton

Lawrence Livermore National Laboratory
P. O. Box 808, Livermore, CA 94550-0808

Over the past 20 years LLNL has pursued the development and use of high energy lasers for target physics experiments in support of inertial confinement fusion (ICF). The technology upon which these efforts have been based is the flashlamp-pumped Nd:glass laser. Although this approach will soon culminate with the construction of the National Ignition Facility (NIF), the advantages of these laser systems have allowed the progress in ICF physics that has been achieved to date. The slow shot rate of once every few hours, however, limits the number and type of experiments and applications that can be pursued. The Mercury laser at LLNL represents a new class of high-power, repetition-rated, solid-state lasers for high-energy-density physics that should be viewed as the first small but significant step toward the emergence of a new technology paradigm for fusion laser drivers.

We have assembled an engineering design for the Mercury laser, which is being built over the next two years for full activation in the year 2000. The laser design includes a Yb-doped strontium fluorapatite gain medium, Yb^{3+}-doped $Sr_5(PO_4)_3F$, (i.e., Yb:S-FAP). This medium offers reduced diode pump laser costs because its storage time (>1 ms) is four times longer than that of Nd-doped glass. We have already grown near full aperture crystals without the need for post-growth annealing to remove cloudiness. The diode lasers used to pump these crystals incorporate a low-cost packaging scheme that provides substantial cost leverage for the four 160-kW pump arrays needed for Mercury. Each pump array incorporates 40 "tiles" where a single tile holds 40 laser diode bars. We have demonstrated the performance of several tiles and have shown that our packaging and heat-sink technology can provide the power, efficiency, divergence, and bandwidth needed for Mercury. The laser system utilizes three subsystems for pulse amplification: a fiber oscillator, a regenerative amplifier, and four beam passes through two power amplifiers. We have completed the thermal modeling and hardware design of the gas-cooled heads for the power amplifiers, and have begun the fabrication of one of the two head assemblies.

In this paper, we describe the progress made in several areas of the engineered laser system, and in modeling the performance of the laser. We have completed the initial extraction propagation modeling for the baseline configuration using the PROP92 code in 2D (x,y,z,t). Based on estimated Yb:S-FAP gain profiles obtained from 0D (z,t) analysis, we have verified that the Mercury goals of a focal spot 5 times diffraction limited containing ~100 J can be accomplished. These calculations included the effects of wavefront distortions obtained from LLNL measurements of actual Yb:S-FAP crystals. We also report on updated modeling capabilities and analyses.

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[1] This work was performed under the auspices of the US DOE by LLNL under contract number W-7405-Eng-48 for the Third Annual International Conference on Solid State Lasers for Application (SSLA) to Inertial Confinement Fusion (ICF), 7–12 June 1998, Monterey, CA.
[2] Further author information - E-mail: orth2@llnl.gov; Telephone: (925) 422-8665; FAX: (925)423-1076.

A High-Damage-Threshold Pinhole for Glass Fusion Laser Applications

N. A. Kurnit and S. A. Letzring

Group P-24, MS E526
Los Alamos National Laboratory
Los Alamos, NM 87545
(505) 667-6002, Fax: 665-4409, kurnit@lanl.gov

Abstract

We are investigating means to fabricatehigh-damage-threshold spatial-filter pinholes that might not besusceptible to plasma closure for relatively high energies andlong pulses. These are based on the observation that grazing-incidencereflection from glass can withstand in excess of 5 kJ/cm^2 (normal to the beam) without plasma formation(N. A. Kurnit and R. F. Harrison, to be presented at CLEO '98). The high damage threshold results from both thecosθ spreading of the energy across the surface and thereflection of a large fraction of the energy from the surface,thereby reducing the field strength within the medium. Resultsof tests to be conducted on such pinholes at the Trident laserfacility will be discussed.

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THIA-4

ACHIEVING AND MAINTAINING CLEANLINESS IN NIF AMPLIFIERS

I. F. Stowers, J. A. Horvath
Lawrence Livermore National Laboratory
PO Box 808, L-490, Livermore, CA 94551

Cleanliness measurements made on the AMPLAB prototype NIF amplifier during assembly, cassette transfer, and amplifier operation are summarized. These measurements included particle counts on silicon witness plates, surface cleanliness measurements using a swipe method, and airborne particle counts. Results are compared with similar measurements made on the Beamlet and Nova lasers and in flashlamp test fixtures. The measurements show the effects of various parameters such as purge rate, location, system volume, internal area, and material selection. Observations of Class 100,000 aerosols after flashlamp firings are discussed, as are the cleanliness issues regarding the use of "line replaceable units" versus conventional disk amplifiers such as those used on Nova and Phoebus.

* Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

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TH1A-3

MECHANICAL HANDLING EQUIPMENT FOR THE ASSEMBLY AND MAINTENANCE OF AMPLAB AMPLIFIERS

J. A. Horvath
Lawrence Livermore National Laboratory
PO Box 808, L-490, Livermore, CA 94551

Assembly of the AMPLAB amplifier, which is based on the NIF design concept, is described. Tests performed on the cassette-based amplifiers in AMPLAB included cleanliness of the assembly process, therefore appropriate cassette assembly, transport and insertion equipment was designed and put into operation. These tools include a vacuum slab gripper, slab handling clean crane, slab cassette positioner, cassette transfer interface between the elevated assembly cleanroom and transport vehicle below the floor, sealed transport vehicle for slab cassette movement between the cleanroom and amplifier, and vehicles for the installation and removal of flashlamp cassettes, blastshields, and frame assembly units. These devices were used for AMPLAB amplifier assembly, system reconfigurations, reflector replacements, and recovery from abnormal occurrences such as flashlamp explosions. Observations are made on the design and operation of these tools in AMPLAB and their contribution to the design of similar mechanical systems for NIF.

* Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

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TU3A-2

PLASMA ELECTRODE POCKELS CELL OF «LASER MEGAJOULE» AT C.E.A.

R. Bailly-Salins, C. Sudres, J. P. Marret

C.E.A. Limeil Valenton
94195 Villeneuve St Georges Cedex
France

The $40x40cm^2$ plasma electrode Pockels cells, which have been developed at LLNL for high energy 4 pass laser amplifier, have been taken up in the «Laser Megajoule» project at CEA. Nevertheless, a few alternative technologies and methods have been taken into account to build the first prototype:

- The frame of both plasma chambers have been cast in one piece of polycarbonate since they are only 2cm thick;
- They are refilled with He+1%O_2 at pressure around 0.1mbar;
- Each chamber is equipped with 20 anodes connected to 10ohms ballast resistors;
- The cold cathodes are made of carbon fibre compound or porous tungsten impregnated with BaO, CaO, and $A1_2O_3$;
- The plasma pulsers are switched by IGBT devices and produce 2000A in 10μs;
- The KDP driver has to produce about 18kV during 2 gaps of time separated by 650ns, according to LMJ project requirements. This is achieved by using 12.5ohms pulse forming lines charged under +9kV and -9kV.

Experimental studies are carried out in various conditions to optimise the conductivity and the homogeneity of the plasma for rapidly and uniformly charging and discharging the KDP crystal between 0 and the half wave voltage.

High Energy Diode-Pumped Solid-State Lasers at Thomson-CSF

J-L. Ayral*, J-P. Hirtz**

***Thomson-CSF Laser / BMDéfense Department ; **Thomson-CSF Laser Diodes**
Route départementale 128; 91404 ORSAY ; FRANCE
Tel : 33.01.69.33.03.51 ; Fax : 33.01.69.33.03.49

Inside the Thomson-CSF Laser company of the Thomson-CSF Group, BMDefense Department designs and builds diode-pumped solid-state lasers for military and nuclear applications. On the other side, BMIndustry Department commercializes solid-state lasers for the scientific and industrial markets.

BMDefense presented at ICF'96 in Paris the design of a diode pumped multipass Nd : Glass amplifier for the LMJ front-end. This amplifier aims at delivering a 1J output energy at low pulse repetition frequency and 1053 nm wavelength, with good pulse-to-pulse stability and specifically adapted temporal and spatial properties.

In this presentation, we describe the achievement of a 300 mJ - 20 Hz diode pumped Nd : YAG high energy oscillator, integrated in a very low volume cavity.

Both the 1J Nd : Glass amplifier and the 300 mJ Nd : YAG oscillator are pumped with high brightness stacked arrays (or « autostacks ») developed by Thomson-CSF Laser Diodes company. This new family of QCW stacked arrays is well adapted for DPSSL at low duty cycle operation (PRF $\leq$ 30 Hz). The stacks can deliver power densities of 10 kW/cm^2 (that is 1000W for an usefull emitting surface of 1x10 mm^2).

When compared with standard commercial QCW stacked arrays, the main benefits of using these high brightness stacks are the following :

. an important cost reduction related to a drastic simplification in the assembling process,

. an improved pumping efficiency associated with the improved brightness (~ a factor of 4), which is the consequence of the reduced pitch between the linear bar arrays.

Inside the 300 mJ oscillator cavity, Nd :YAG slabs are transversely pumped with up to 18 kW of diode pumping power. The optical-to-optical efficiency is 12%. The temporal and spatial parameters of the 300 mJ output pulse are respectively a pulse length between 12 to 18 ns and a M^2 factor between 5 and 8.

The 300 mJ oscillator is integrated into a low volume around 2 liters. This is achieved thanks to the high power density of the pumping stacked arrays, and to an original folded cavity design. This oscillator scheme is aimed to be integrated in the near future with compact electronics, for airborne applications.

Thermal management of the laser can be achieved by forced air, even in harsh environmental conditions, through the use of thermoelectric modules for the temperature regulation of the laser diodes. So any liquid cooling can be avoided, leading to an improved reliability.

This compact pumping architecture demonstration gives a high level of confidence in the diode-pumped 1J Nd : Glass amplifier design for the LMJ front-end.

The main characteristics of the 300 mJ diode pumped Nd : YAG oscillator, as well as the high brightness stacked arrays, will be described in the presentation.

Replication of high power laser diffractive optical component

Philippe Belleville[1], Sophie Kaladgew[2] and Philippe Gacoin[3]
[1]CEA - Centre d'Études de Limeil-Valenton
94195 Villeneuve Saint Georges Cedex - France
phone +33 01 45 95 61 82 / FAX +33 01 43 86 74 07
[2]REOSC 91280 St-Pierre-du-Perray - FRANCE
[3]JOBIN-YVON SA 91160 Longjumeau - FRANCE

Key words: **replication, diffractive laser optics, fluoropolymer, embossing, molding.**

This abstract has been prepared for submittal to the Third Annual International Conference on SSLA to ICF to be held in Monterey, California, June 7 - 12, 1998.

Abstract

The Centre d'Études de Limeil-Valenton is currently involved in a project which consists of the construction of a 1.8 MJ/500TW (351-nm) pulsed Nd:glass laser and which will be devoted to Inertial Confinement Fusion (ICF) research in France. In this 240 laser beam facility, diffractive optical components will be used for high-efficiency color separation, steering and focusing of each laser beam towards laser/matter interaction target. To reach so many requirements, a laser chain architecture using focusing diffractive gratings has been selected. Moreover, in order to decrease making cost of the final hundreds of elements, a replication process is under evaluation. Main issues for obtaining a reliable replication process are related to the groove depth and step width of the profile needed to achieve high efficiency (>95%) gratings. Replication process results using both embossing and molding techniques on a thermoplastic laser damage-resistant polymer will be discussed. Achievement of satisfactory replica were obtained after polymer adhesion enhancement, development of a specific releasing agent, and selection of critical parameter such as step processing temperature.

Laser-cavity mirror preparation using sol-gel chemistry and laminar-flow coating technique

Philippe Belleville[1] and Philippe Pégon[2]
[1]CEA - Centre d'Études de Limeil-Valenton
94195 Villeneuve Saint Georges Cedex - France
phone +33 01 45 95 61 82 / FAX +33 01 43 86 74 07
[2]REOSC 91280 St-Pierre-du-Perray - FRANCE

Key words: **sol-gel chemistry, mirrored coating, composite material, room-temperature deposition.**

This abstract has been prepared for submittal to the Third Annual International Conference on SSLA to ICF to be held in Monterey, California, June 7 - 12, 1998.

Abstract

The CEA/DAM megajoule-class pulsed Nd:glass laser devoted to Inertial Confinement Fusion (ICF) research will require 240 cavity-end mirrors. The approved laser design necessitates 44-cm x 44-cm x 6-cm highly-reflective (HR)-coated substrates representing more than 50-m^2 of coated area. Prototypes of these dielectric mirrors were prepared with interference quaterwave stacks of SiO_2 and ZrO_2-PVP (PolyVinylPyrrolidone) thin films starting from sol-gel colloidal suspensions (sols). Low refractive index material was based on nanosized silica particles and high refractive index coating solution was made of an inorganic-organic composite system. A promising deposition technique so-called "Laminar Flow Coating" (LFC) has been evaluated for HR laser damage-resistant sol-gel coating development. The LFC-machine is using substrate in an upside-down position and a travelling wave of coating solution is laminary transported under the substrate flat surface with a tubular dispense unit. Thin-film so created by the solvent evaporation is then dried at room-temperature or using short wavelength UV-curing built-in station. Results regarding coating uniformity, edge-effect, 1053-nm reflectance and laser-damage threshold will be discussed.

A sol-gel broadband antireflective and scratch-resistant coating for megajoule-class laser amplifier blastshields

Philippe Belleville and Philippe Prené
CEA - Centre d'Études de Limeil-Valenton
94195 Villeneuve Saint Georges Cedex - France
phone +33 01 45 95 61 82 / FAX +33 01 43 86 74 07

Key words: **sol-gel chemistry, antireflective coating, abrasion-resistance, layer-densification process.**

This abstract has been prepared for submittal to the Third Annual International Conference on SSLA to ICF to be held in Monterey, California, June 7 - 12, 1998.

Abstract

A novel optical coating devoted to reduction of specular reflection has been developed using the sol-gel route. The sol-gel antireflective (AR) coating is made from tantalum and silicon oxide-based solutions. First layer (high refractive index) is deposited from a solution based on polymeric tantalum oxide. Second layer (low refractive index) is containing silica polymeric matrix in order to get a double-layer optical stack. Sol-gel synthesis have been carried out starting from cheap precursors in order to produce metallic alkoxide-based solution, each one suitable for liquid-deposition technique use such as dip-coating. After layer deposition, a curing step is required. Both thermal and UV-curing could induce layer densification and generate final coating properties. Thermal baking step does not exceed 150°C temperature. This two-layer antireflective coating has been optimized to offer scratch-resistance (in compliance with US-MIL-C-0675C severe test) allowing easy-cleaning and also broadband antireflection property onto various substrates. Experiments of AR-coating deposition onto large-area high-power laser glass plates (1811x635x6-mm in size) will be described. Based on calculations, the amplification yield using such a sol-gel coating onto LMJ-blastshields is evaluated to be *ca.*7%.

SYNCHRONIZATION SYSTEM OF LMJ, APPLICATION ON THE LIL SYSTEM

Dominique MONNIER-BOURDIN, Alain HERVE, Olivier LUTZ
Centre d'Etudes de Bruyères le Châtel
DRIF / DCRE / SEIM / L2E
91680 Bruyères le Châtel BP12
Tél : 01-69-26-62-01, fax : 01-69-26-70-43
Présentation orale

The Laser MegaJoule (LMJ) is made of 240 independant laser beams. It must deliver a power of 2 millions Joules in a few nanoseconds. This is only possible if all the bundles focus on the target at the same time.

The object of our system is to synchronize the laser pulses on the target in a temporal window of 60 ps ($60\ 10^{-12}$s). It must ensure the coherence of the triggering of laser pulses and measurement systems. The number of synchronization signals for the LMJ is higher than 8000. They are spread out over an area of about 10000 m² with a relative accuracy that can reach 15 ps RMS between outputs (60 ps peak to peak), along single or recurrent shot. The GPS system, which is by comparison one of the best synchronization systems, has a relative accuracy of a few ns.

CEA is studying a solution based on the principle of a high rate optical digital link, with low jitter ensuring the transport of a temporal reference in all useful areas of the building. This concept relies on two kinds of devices : the master system and the slave system. The master continuously delivers a digital clock message over a 1 kilometer long single mode fiber network. Finally, the master system manages the trigerring by dispatching specific commands within the digital message and corrects the drift of transit time of fibers (35 ps/°C).

The slave system localy regenerates a synchronous clock phased in with the master system. It analyses the numerical message to generate electrical start pulses over a 50 µs delay range with a maximum jitter of 15 ps efficient. A supervision system manages the databases including all information to program each channel of each slave system (delay, functionning, ...).

To reach the goals of the Ligne d'Intégration Laser (LIL) in terms of synchronization, CEA is developing large dynamic delay generators with low jitter in collaboration with IN-SNEC (INTERTECHNIQUE corporation). This solution has no equivalent on the market today.

We have reached the following performances : delay range of up to 1 s, accuracy of 5 ps on the best channel, and a rms jitter between channels lower than 30 ps over the full programmable delay range.

Efficient frequency tripling of 1.05µm 300fs chirped pulses : a new approach for a petawatt laser at 351 nm.

F. Raoult[1], A. C. L. Boscheron[1], D. Husson[1], C. Rouyer[1], C. Sauteret[1] and A. Migus[2]

1. Commissariat à l'énergie atomique, Centre de Limeil-Valenton, 94195 Villeneuve St.Georges Cedex, France
Tél 33 1 45 95 67 38, Fax 33 1 43 86 74 07

2. Laboratoire pour l'Utilisation des Lasers Intenses, CNRS UMR 100 Ecole Polytechnique, 91128 Palaiseau Cedex, France

Summary

Picosecond and femtosecond energetic pulses are difficult to produce in the UV domain. One approach consists in excimer lasers but with limited performances, the other one in frequency doubling or tripling solid state laser outputs. The difficulty in the latter case lies in the phase-matching condition which limits the emitted bandwidth. Therefore the pulse cannot be short when using long crystals while the efficiency gets low in case of thin crystals.

We recently publish an idea based on the manipulation of pulses with appropriate chirps for maintaining phase matching over the whole bandwidth [1] in order to circumvent this issue and efficiently generate broadband harmonics. Basically, two different chirps are created which can be described as frequency laws versus time : $\omega_1(t)=\omega_0+b_1t$ and $\omega_2(t)=\omega_0+b_2t$. In case of frequency tripling, one of this pulse is frequency doubled so that the pulse chirp becomes $\omega'_2(t)=2\omega_0+b'_2t$. The principle of the technique is that the sum $\omega_1(t)+\omega'_2(t)$ has to follow the phase matching law plotted on Fig.1 in order to maintain phase matching for third harmonic generation, and therefore provides a large bandwidth with an efficiency as large as with the monochromatic case. For KDP and 1.05µm type II tripling, this curve is linear in a large spectral range

corresponding to a slope of $b_2'/b_1 = -5.17$ and is compatible with pulses as short as 100fs.

In order to verify this idea, we perform an experiment using a Ti:sapphire femtosecond laser and a CPA amplifier configuration based on a Ti:sapphire regenerative amplifier and Nd:phospate glass head. Our system delivers 1ns chirped pulses with 100mJ energy which can be compressed to duration of the order of 300fs. The frequency converter consisted in a KDP Type I- Type II collinear configuration as shown in Fig.2. In order to estimate the performance we use as a reference a configuration with identical chirped pulses at 1.05μm (55ps duration FWHM). We verified that the third harmonic spectral shape (FWHM : 0.12 nm) corresponds to the expected sinc^2 wavelength tuning curve of a 3cm type II 3ω-KDP crystal (Fig.3a). In this case the conversion efficiency is 4%. In a second experiment one of the compressor grating is translated in order to introduce the chirp needed to get the slope of -5.17. This corresponded to mixing a 133ps-1.05μm pulse and a 38ps-0.53μm pulse obtained by frequency doubling the initial 55ps-1.05μm pulse in a 2cm type I KDP. As shown on Fig.3b, we obtain a third harmonic spectral bandwidth of 1.2nm, 10 times the reference bandwidth, limited only by the initial pulse spectrum. The incident energies on the 3ω-crystal at 1.05μm and 0.53μm were 21 mJ and 7.5mJ, the output at 351nm 5.3mJ, respectively. Scaling to the 2ω pulse duration, the overall efficiency is 40%.

These experiment realized at a small scale level can directly be upgraded to NIF or LMJ amplifiers. The bandwidth we produce allows to get 300fs pulses at 351nm. First experiment are underway to compress these pulses using a grating pair compressor. We note that this would imply large UV gratings which are anyhow in development for the LMJ project. In conclusion, a petawatt class laser can be built at 351nm using NIF or LMJ technologies. This UV approach may be more competitive in the fast ignitor scheme than using longer wavelength laser because it allows to avoid generating a too hot population of electrons.

References

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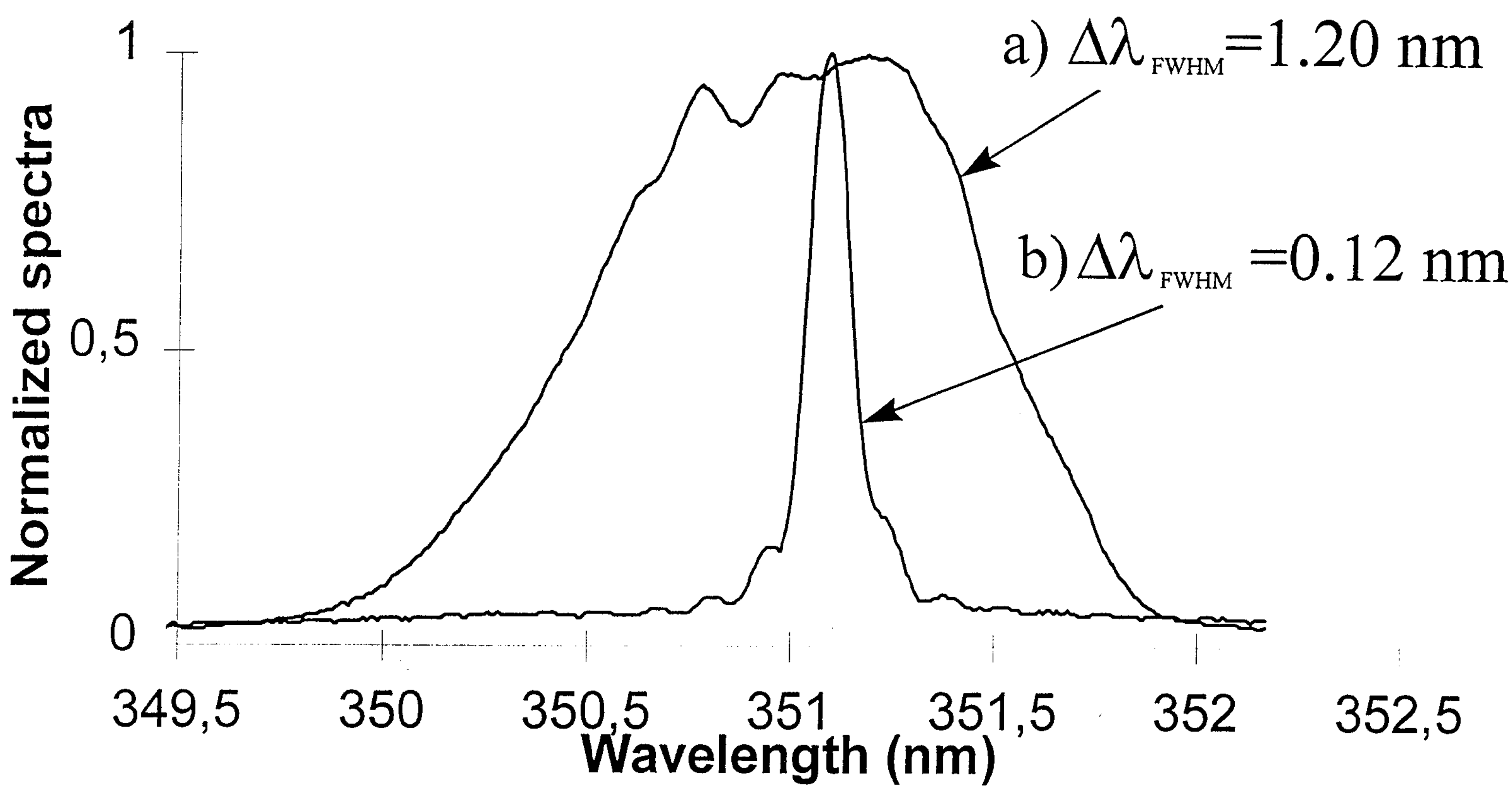
Figure captions

Fig. 1 Phase matching curve for mixing ω_1 and ω_2 in a tripling type II KDP (θ=59°). This curve is linear in a large spectral range for the frequency ω_0 we consider.

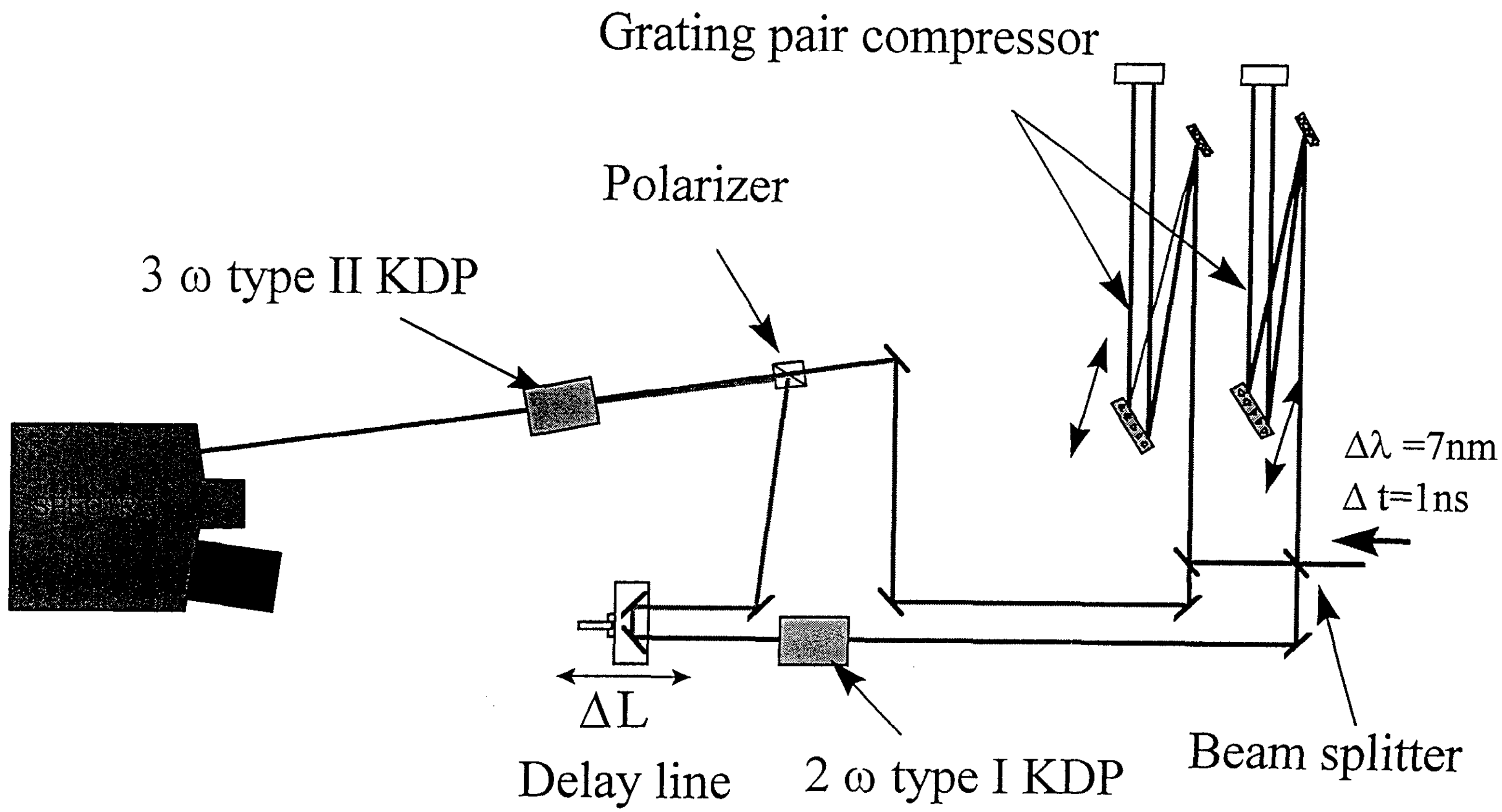
Fig. 2 Experimental setup of broadband third harmonic generation. Different chirps can be created by using two different compressors.

Fig. 3 Third harmonic relative phase matching efficiency versus wavelength using a 2 cm type I 2 ω-KDP and a 3 cm type II 3 ω-KDP . The lower curve shows the third harmonic spectrum obtained with a classical configuration. The upper curve shows the third harmonic spectrum obtained with appropriate chirped pulses for maintaining phase matching over the whole bandwidth.

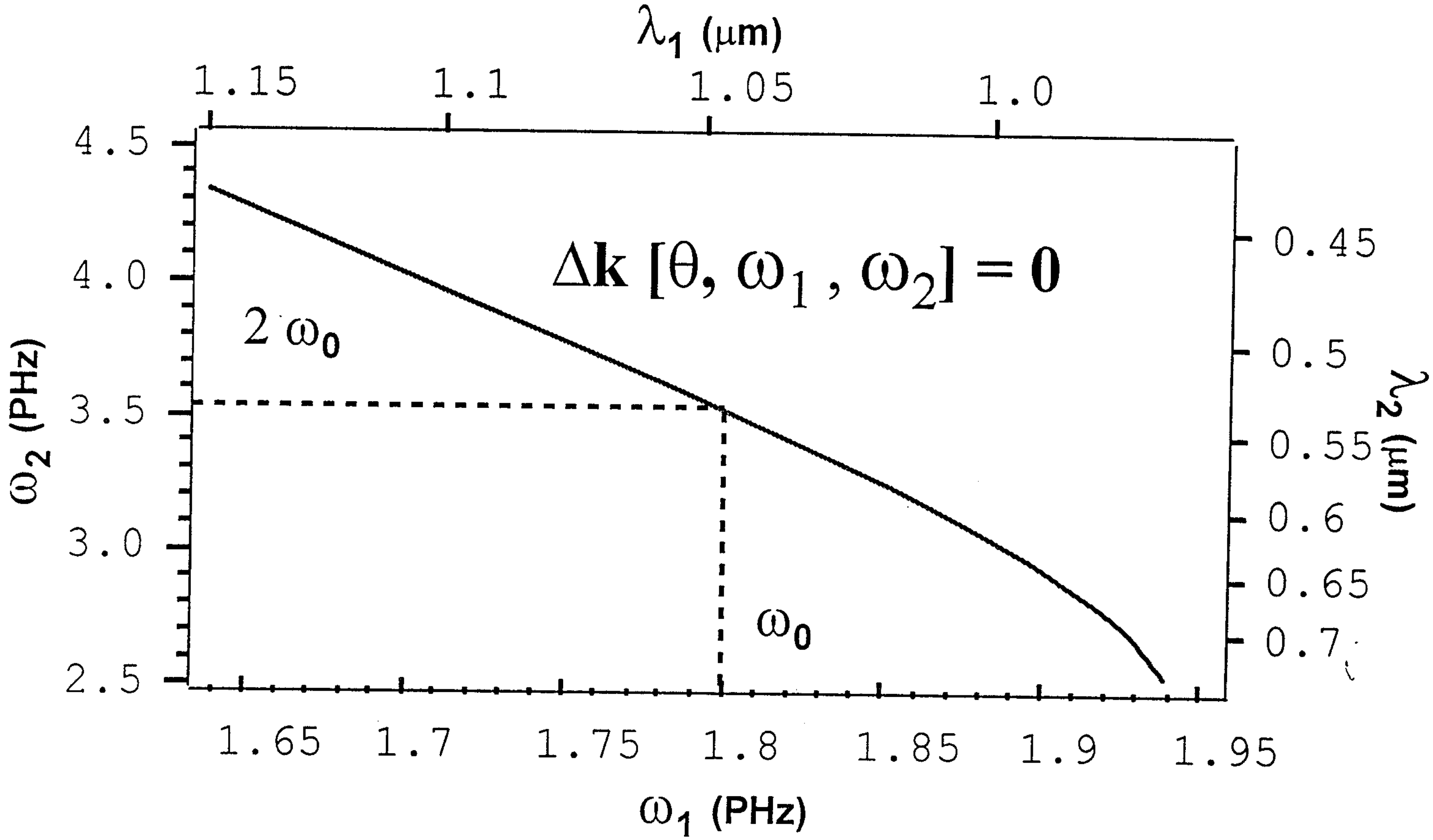
F. Raoult et al., Efficient frequency tripling... Fig. 3



F. Raoult et al., *Efficient frequency tripling...* Fig. 2



F. Raoult et al., Efficient frequency tripling... Fig. 1



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TH1A-5

FROM FILTER TO ALL FILM ENERGY STORAGE CAPACITORS

Michel Bramoullé,* Jean-Pierre Marret,** Pierre Michalczyk*

*Thomson CSF Passive Components
Avenue du Colonel Prat
21850 Saint-Apollinaire France
Telephone (0)3.80.71.75.53 Fax (0)3.80.70.13.47

**Commissariat a l'Energie Atomique
Centre d'Etudes de Limeil-Valenton
94195 Villeneuve-St-Georges France
Telephone (0)146956000 Fax (0)143867406

Energy storage capacitor technology has always been based on that of filter capacitors. It started with the paper-aluminum foil, impregnated by mineral oil and later by castor oil and continued by a mixed dielectric-foil. Significant improvements were made by the replacement of the aluminum foil by the metallization of a dielectric layer.

At the end of the 80's, in order to significantly reduce the volume and the weight and to fully secure the end of life on large filter capacitor banks used in the traction field, a new design was settled based on a compromise between a polymer film, surface segmented metallization and a vegetable impregnant.

The polymer film, a bi oriented polypropylene, has a very low D.F., a high level of breakdown, a low number of weak points per square meter, and is produced in very large quantities with high reliability.

To make the capacitor more secure, it was necessary to use metallization, with appropriate surface segmentations, designed to limit the inrush energy at the film breakdown point. At the end of life, only 2% of the initial capacitance was lost without any bulging of the can.

Because swelling of the film and metallization are non compatible, it was necessary to select an adequate impregnant which has, besides, high gassing properties. Rapeseed oil fulfilled these requirements; its high fire and flash points also enhance the safety properties of the capacitors.

Tens of thousand large capacitors, based on this technology, have been produced to date, and are working, without any failure.

In the 90's the requirements for large energy storage capacitors banks also insisted on secured, low price products. The excellent results obtained on more than 25 000 filter capacitors, led to study the technology transfer from filter to energy storage capacitors, in cooperation and with the support of the CEA.

All the knowledge acquired especially in the range of the short working times and subsequently high stresses, and in the peak current occurring in the faulty conditions of the filter capacitors were applied to the energy storage field.

The 3 - base components remain the same. Particular studies are carried out the polypropylene film properties, and mainly on the breakdown level, depending on the batches delivered and the thickness of the film; this evaluation is essential, regarding the high working stress used in the capacitors.

The metallization characteristics are deeply modified in order to minimize the energy needed in the self healing process, and to avoid the puncture of the close film layers; also, because the high stresses and therefore the number of the breakdown points, a fundamental change is operated in the segmentation mode, to reduce the capacitance area eliminated at each film breakdown.

The special gassing properties of the impregnant are fully employed, especially in the lifetime tests in which the repetition rate are high and far from the normal working conditions. All these results are obtained on industrial dimensions samples, using systematically normal size windings.

3 basic types of tests are described - d.c and discharge step tests completed by discharges tests on large units. They are implemented by the characteristics of this technology regarding the stand by-time and the voltage reversal.

The performances obtained with this technology depend on the improvements, which might be expected, on the polypropylen film; impurities added during the chemical processing of the resin, and the electrostatic charges included inside the film, limit its dielectric properties. This situation could be modified in the near future when using other catalysts, and an other pre-metallizing mode. On the other hand, and up to now, all the improvements on the metallization were more based on the segmentation. Due to the thickness of this metal, the kind of metal used today could be changed to enhance the self healing properties.

Finally, from a mechanical point of view, a description of an integrated solid-states switch in the capacitor gives one solution for the future equipments.

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W4B-3 → MP

Temporal response diagnostic for the *Laser MégaJoule*

P.LECLERC, V.ALLOUCHE
Commissariat à l'Energie Atomique (CEA)
CEA-DAM
DCRE/SEIM/L2E
BP 12
91680 BRUYERES LE CHATEL
Tel. : +33.1.69.26.47.71 - Fax. :
e-mail : leclerc@bruyeres.cea.fr

Abstract :

The *Laser MégaJoule* requires very precise beam-to-beam power balance. Moreover, each laser pulse will have a particular temporal response to generate specific effects such as mechanical compression, plasma heating, and ignition. To control the good operating of the facility, several kinds of measurement systems have to be developed for beam diagnostics. The temporal shape diagnostic is a critical one.

The LMJ will generate 20 ns wide pulses with a peak-to-foot contrast ratio of up to 300 :1, with a rise time as short as 100 ps. The pulse shape must be known with a 2% accuracy (rms error on a 2 ns sliding window), and the diagnostic system must check that the extinction ratio is above 10^5 before the foot of the signal.
To achieve such performances, the temporal shape diagnostic must have a dynamic range of 7500, and a bandwidth near 10 GHz. It must also be as less expensive as possible to be implemented on 3 locations per beam (meaning a need for 720 diagnostic systems).

An original design had to be found to face that specific need that exceeds the capabilities of standard instrumentation. We propose a diagnostic system built around a commercial real time digitizer and two optical receivers. The use of optical fibers allows vertical multiplexing of several signals to increase the measurement dynamic while temporal multiplexing reduces prices. Operating receivers and digitizers above their maximum ratings was carefuly studied, with special concern for linearity, and recovery time after saturation. The study of the optical injection system was also a critical point.

Modeling and characterizations have been performed on the different sub-parts to validate our measurement system. Then a global validation campaign was conducted on the *Phebus* laser facility. It showed that our diagnostic reaches the needed dynamic range at an acceptable price. But its bandwidth is limited at 1 GHz, thus restricting temporal response diagnostic to 1 ns rise-time pulses (or 500 ps with some restrictions).

Temporal response diagnostic for the LMJ using a commercial digitizer appears to be a valid concept, but some enhancements are still needed. We keep working on that system to adapt it to 3ω wavelength, to automate the optical injection system and to enhance its bandwidth by using new types of real time digitizers.

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TU1A-2

INTEGRATED OPERATIONS OF THE NATIONAL IGNITION FACILITY (NIF) OPTICAL PULSE GENERATION DEVELOPMENT SYSTEM

J.K. Crane, R.B. Wilcox, N.W. Hopps,[1] D. Browning, M.D. Martinez, B. Moran, F. Penko, J.E. Rothenberg, M. Henesian, C.B. Dane, L.A. Hackel

Lawrence Livermore National Laboratory
P.O. Box 808, Livermore, California 94551

[1]Atomic Weapons Establishment, Aldermaston, Reading, RG7 4PR
United Kingdom

We describe the Optical Pulse Generation (OPG) testbed, which is the integration of the OMR and Preamplifier Development Laboratories. We use this OPG testbed to develop and demonstrate the overall capabilities of the NIF laser system front end. We will present the measured energy and power output, temporal and spatial pulse shaping capability, prepulse, and temporal pulse fidelity of the OPG system and compare these results with the required system performance specifications. We will discuss the models that are used to predict the system performance and how the OPG output requirements flowdown to the subordinate subsystems within the OPG system.

Work done under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

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TP

High gain Preamplifier Module (PAM) engineering prototype for the National Ignition Facility (NIF) laser system

Mikael D. Martinez, Kenneth M. Skulina, Fred J. Deadrick, John Braucht, Bob Jones, Steve Hawkins, Ron Tilley, Ron Wing, Jim Crawford, Don Browning, and Frank Penko

Lawrence Livermore National laboratory
7000 E. Avenue, M.S. L-483, Livermore, CA 94550
(925) 423-3914 PH; (925) 422-9554 Fax; martinez31@llnl.gov

We describe the preamplifier module (PAM) engineering prototype which is a subsystem in the NIF Optical Pulse Generation (OPG) system. The PAM is comprised of a diode pumped, Nd:glass regenerative amplifier, an intermediate beam shaping subsystem, a flashlamp pumped multipass amplifier, and an electronics control system, all contained within a line replaceable unit (LRU). A separate master oscillator provides a specially tailored 1nJ pulse at 1053nm that is injected into the PAM where the diode-pumped regenerative amplifier increases the energy to 25mJ. The beam shaper then expands and spatially shapes the beam for injection into the multipass amplifier which brings the energy to 22J. The system gain of the PAM is 10^{10}.

The optical systems are installed on both sides of a vertically oriented optical table, contained within a contamination controlled environment. Precision wheels and rails provide alignment and the ability for line replacement of entire PAM units. A separate electronics bay is thermally and vibrationally isolated from the optical train, and allows sufficient *in situ* access for electrical maintenance.

All laser control and diagnostic hardware is located in the electronics bay. Each PAM includes an embedded VME based processor and computer control modules, which are interfaced via a distributed network to the NIF Integrated Computer Control System for remote laser operation.

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TH2A-3

GAIN AND WAVEFRONT MEASUREMENTS PERFORMED ON THE NIF/LMJ PROTOTYPE AMPLIFIERS*

L. Zapata, C. Marshall, M. Rotter, K. Jancaitis, A. Erlandson

Lawrence Livermore National Laboratory
P.O. Box 808, L-490, Livermore, CA 94551

and

E. Grebot, J. Beuillier, J. L. Guenet, S. Seznec
Commissariat à l'Energie Atomique
Centre d'Etudes de Limeil-Valenton
Boite Postale 25
Veilleneuve, St. Georges, FRANCE 94190

The National Ignition Facility (NIF) in the US and the Laser Mega Joule (LMJ) in France when completed, will be stadium sized solid state laser systems comprising 192 (NIF)/240 (LMJ) beam lines that will deliver 1.8 MJ, 500 TW at 0.35 μm to the fusion target where they will demonstrate inertial fusion ignition. These mega-joule class lasers will also be applied to missions in national security, energy and science applications. Our group is involved in the development of the 3072 large Nd:glass amplifiers, from which the NIF/LMJ laser energy will be derived. In the present design, the amplifiers will comprise bundles of 4-cm-thick Nd:glass slabs positioned at Brewster's angle, arranged in columns 4-slabs-high, two columns wide. Each beam line aperture will be 40 cm by 40 cm. Full scale NIF/LMJ prototype amplifiers are being tested in the amplifier laboratory (AMPLAB) at Lawrence Livermore National Laboratory. Physics and engineering issues are being elucidated in our full scale test-bed. In this paper we discuss measurements aimed to verify the optical performance of the NIF/LMJ amplifiers against the variables that affect it in order to optimize the amplifier performance. The validation/refinement of the physics codes used in the design of these amplifiers is our ultimate goal.

A Large Aperture Diagnostic System (LADS) has been built in order to provide time and spatially resolved measurements of gain and wave front distortions over the full 40 cm by 40 cm aperture. The system is able to address each of eight apertures by a system of motorized stages and following a semi-automated alignment procedure, take data on the aperture of interest. The major components for the LADS are the probe laser, the optical relay system, the gain measurement section, and the wave-front measurement (interferometer) section. The LADS has enabled us to obtain high quality data, to ascertain the performance of the NIF/LMJ amplifiers.

The Nd:YLF probe laser operates at 15 Hz providing 20 ns, 50 mJ/pulse, single frequency pulses at 1.053 μm. The beam is expanded 240x by a system of afocal telescopes that relay an aperture to and from the back mirror. The system is aligned and focused to include strategic relays from a square aperture, to a beam-splitter in the diagnostics area and to/from the back mirror. The expanded beam fills the aperture defined by a mask residing at the laser slabs. An image of the input (reference) beam is split and relayed to a 1000x1000 pixel scientific CCD. A pyroelectric detector also integrates this reference. Upon return from the back mirror, after a double pass through the amplifiers, the (probe) beam is split, relayed to another scientific CCD and integrated by a second pyroelectric detector. Timing signals are provided to the instrumentation so that the samples are acquired at the time of interest. Interferometry is done similarly by relaying the probe beam to a camera however, with the addition of a reference beam superimposed in a Twyman-Green arrangement. The reference wavefront is provided by a polarization-maintaining, single-mode fiber of appropriate length to match the round trip delay. There are two cameras collecting the pulsed interferograms by means of a 50/50 splitter this way, two closely spaced interferograms can be obtained. We generally obtain wavefront data separated by 75 ms, the minimum allowed by our laser repetition frequency. We have verified that the wavefronts obtained, have an accuracy of $\lambda/50$.

A complete set of gain and wavefront measurements has been collected and includes the "V", "X" and "Diamond" configurations for each of the 4-high apertures available in the AMPLAB. From these, the performance of the N-long amplifier chains planned for the NIF/LMJ can be extrapolated. The results are consistent with the 5%/cm gain expected for the NIF/LMJ. The wavefront "W" shape expected is evident from the measurements however, the magnitude for the peak-to-valley is 0.8 waves, is higher than initially expected. The reasons are being elucidated at the time of this writing and will be presented.

Pump-Induced Wavefront Distortion in Prototypical NIF/LMJ Amplifiers - Modeling and Comparison with Experiments*

Mark Rotter, Ken Jancaitis, Chris Marshall, Luis Zapata, and Al Erlandson
Lawrence Livermore National Laboratory
P.O. Box 5504 L-490
Livermore, CA., USA 94551

and

Geoffroy LeTouzé & Olivier Cabourdin
Commissariat a l'Energie Atomique
Centre d'Etudes de Limeil-Valenton
Boite Postale 27
Villeneuve, St. Georges, FRANCE 94190

Abstract

We are currently developing large-aperture amplifiers for the National Ignition Facility (NIF) and Laser Megajoules (LMJ) lasers. These multi-segment amplifiers are of the flashlamp-pumped, Nd:Glass type and are designed to propagate a nominally 36 cm square beam. The apertures within a particular amplifier bundle are arranged in a four-high by two-wide configuration and utilize two side flashlamp arrays and a central flashlamp array for pumping. The configuration is very similar to that used in the Beamlet laser, a single-beam prototype for the NIF/LMJ lasers, which has four apertures arranged in a two-high by two-wide configuration.

As a result of the geometry of the amplifier, the front and back faces of the laser slab are heated unevenly by the pump process. This uneven heating results in a mechanical deformation of the laser slab and consequent internal stresses. The deformation and stresses, along with a temperature-dependent refractive index variation, result in phase variations across the laser beam (so-called pump-induced wavefront distortions). These phase variations lead to beam steering which may affect frequency conversion as well as energy-on-target. In order to accurately predict system performance, the pump-induced wavefront distortions for a given amplifier module must be determined.

We have developed a model which allows us to estimate the pump-induced wavefront distortion for a given amplifier configuration. The model calculates the spatially-resolved optical-path differences through the laser slab for various contributions: temperature-dependent refractive index changes, stress-induced refractive index changes, and mechanical deformation. The model also calculates the spatially-resolved depolarization.

We will describe various aspects of the model and present comparisons between the model and experimental data taken on AMPLAB, our amplifier test laboratory.

* Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract No. W-7405-ENG-48

Frequency Doubling of Multi Terawatt Picosecond Pulses for Plasma Interactions

CN Danson, R Allott, JL Collier, CB Edwards, P Flintoff, MHR Hutchinson, D Neely, DA Pepler, IN Ross, *M Trentelman and T Winstone

CLF, Rutherford Appleton Laboratory, Chilton, Didcot, Oxon, OX11 0QX, UK
Telephone: (0)1235 821900 Fax: (0)1235 445888 D.Neely@rl.ac.uk
*Current Address: ASML, Einhoven, The Netherlands

We report on experiments to frequency double the 30 J, 50 TW sub picosecond pulse of the VULCAN chirped pulse amplified (CPA) beam [1] for laser matter interaction studies at the Central Laser Facility. Efficiencies of > 50% have been achieved.

User demand for harmonic conversion of the CPA output of Vulcan is increasing. This arises for a number of reasons: there is a reduction of the pedestal level by virtue of the non-linear nature of the doubling process; a shorter wavelength interaction beam couples more efficiently to the target in laser-plasma experiments; and shorter wavelengths are also required for studies of high harmonic generation due to the higher efficiency of lower order processes.

Frequency doubling tests on small aperture KDP crystals between 1 - 4 mm thick at a range of incident intensities up to 3×10^{11} W/cm^2 are reported. The crystals used type I phase matching which has almost equal group velocities for the fundamental and second harmonic. We present results on the second harmonic energy and conversion efficiency as a function of power density and pulse length of the drive laser.

Calculations based on the effects of noise amplification and B integral on the final beam focusability will be described and compared to tests carried out on a large 140 x 89 x 4 mm KDP crystal. The optimum crystal thickness to achieve maximum beam brightness as a function of power density and pulse length are discussed.

We report on the characterisation of these pulses in a plasma wake-field experiment, where pulses in excess of 10 TW were delivered to target in the frequency doubled beam [2].

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THE NIF POWER BALANCE*

Ogden S. Jones, D. Ralph Speck, and Steven W. Haan
Lawrence Livermore National Laboratory
P.O. Box 808, L-4, Livermore, California, U.S.A. 94551
(510) 423-1872 FAX (510) 423-9208
jones96@llnl.gov

ABSTRACT

The ICF ignition targets require careful balancing of the power amongst the 192 beams that irradiate them. The baseline system is designed to provide 8% rms power balance for the baseline indirect drive and direct drive targets. Power imbalance is due both to repeatable and shot-to-shot differences among beams. Repeatable differences in beam performance are due to unavoidable differences in transmission, gain, and frequency conversion efficiency of the components that make up each beam. They are compensated for in two ways. The input pulse shape for each set of four beams ("quad") is adjusted to give each quad the same output pulse shape. Differences among beams within a quad are compensated for by adjusting the input energy to each beam. Shot-to-shot differences are caused by jitter in the optical pulse generation (OPG) system output, the amplifier gains, and the frequency converter efficiencies. The allowable jitter for each of these subsystems has been set such that the laser as a whole meets the 8% system requirement.

This problem was analyzed using the BTGAIN code, which solves for either the input or the output pulse shape for a chain of active and passive laser components, given the pulse shape at the other end of the system. Key features are that the amplifier slabs are modeled using Frantz-Nodvic theory to account for amplifier saturation, and each component is assigned a transmission to model distributed losses. Frequency tripling efficiency is modeled with a patch to the code that includes deviations from the optimum phase matching angle to account for fabrication and alignment differences among the tripler assemblies. First, a 192-beam model was built, with each beam made up of components whose gain, transmission, or deviation from phase matching angle was randomly selected from a Gaussian distribution representing component tolerances. Then a series of Monte Carlo calculations were performed to determine the optimum strategies for compensating for repeatable differences among beams and to determine the allocation of shot-to-shot errors among subsystems in order to meet the power balance requirement. Detailed results from these calculations will be presented.

*Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

PREPULSE OF THE NIF LASER SYSTEM*

David H. Munro, Jerome M. Auerbach, and David M. Gold
Lawrence Livermore National Laboratory
P.O. Box 808, L-477, Livermore, California, U.S.A. 94551
(510) 422-5428 FAX (510) 423-9208
munro1@llnl.gov

ABSTRACT

We discuss the origins of prepulse for the National Ignition Facility (NIF) Laser, and estimate the prepulse brightness as a function of time before the arrival of the main pulse. We also show the results of experiments to measure prepulse damage to fusion capsule surface finish. The current prepulse estimates are near or below the level which could cause significant damage to a beryllium capsule surface. Finally, we describe a technique for reducing the prepulse at the target to even lower levels, should that prove necessary.

*Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

Laser Beam Propagation and Interaction in Pinhole Plasmas Including Plasma Kinetic Effects

B. B. Afeyan[1], J. P. Matte[2], R. P. Ratowsky[3], C. D. Boley[3], K. G. Estabrook[3]

University of California
Lawrence Livermore National Laboratory
Livermore, CA 94550 USA
E-mail: afeyan1@llnl.gov
Phone: (510) 422-3848; Fax: (510) 606-5383

ABSTRACT

We present new results describing the propagation and interaction of high intensity laser beams in plasmas that are characteristic of various pinhole designs envisaged for the NIF spatial filters. We concentrate on three physical phenomena: 1) Kinetic (Fokker Planck) simulations of the plasma evolution with various ionization models and comparisons with strictly fluid codes. Specifically, Ta and Fe plasmas are modeled in order to compare the resulting density and temperature profiles obtained from the various codes. 2) A nonlinear analysis of the laser beam as it propagates in a realistic pinhole plasma and backscatters. We present density and intensity profile criteria which demarcate the stability boundary for significant Raman backscatter. We use anisotropic and non-Maxwellian electron velocity distribution functions that are characteristic of pinhole plasmas. 3) We use 2D and 3D spectral and finite difference beam propagation codes to simulate the evolution of the laser electric field inside pinhole plasma density models derived from interferometry data or fluid simulations and compare the electric field's amplitude and phase to those due to vacuum propagation. Our aim is to establish when certain phase screen approximations are appropriate and when more complete theory might be warranted. Whenever possible, we attempt to make contact with experimental measurements on OSL and Beamlet.

[1]Polymath Associates, Livermore, CA 94550
[2]INRS Energie-Materiaux, Quebec, Canada, J3X-1S2
[3]LLNL, Livermore, CA 94550

This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory, under contract number W-7405-ENG-48.

UCRL-JC-129864

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W3B-2

Pinhole Closure Measurements

D. Milam, J.E. Murray, K.G. Estabrook, C.D. Boley, W.D. Sell,
N.D. Nielsen, R.K. Kirkwood, B.B. Afeyan*, Y.A. Zakharenkov

University of California
Lawrence Livermore National Laboratory
Livermore, CA 94550 USA
E-mail: Milam1@llnl.gov
Phone: (510) 422-5499; Fax: (510) 423-5517

ABSTRACT

We have used an off-line laser and Beamlet to determine intensity and scaling relationships for pinhole closure and to observe closure in pinholes of varied geometry. In both facilities a probe beam that was one leg of an interferometer was passed through the pinhole, and streaked interferometry was used to observe the phase change in the plasma that was induced by the main pulse.

Scaling relationships were measured in the off-line facility called the Optical Sciences Laser (OSL). Pinhole and knife-edge samples were irradiated in vacuum by 5-20 ns 1053-nm pulses at edge intensities to 500 GW/cm^2. The knife edges were fabricated from materials of varied atomic mass, M: carbon, aluminum, stainless steel, molybdenum, tantalum and gold. For all of these materials, the phase change fell exponentially with increase of the distance from the edge. The expansion was characterized by the velocity of the contour for a 2π phase change, $V_{2\pi}$. To within experimental uncertainty, $V_{2\pi}$ was relatively constant during a particular irradiation. It increased linearly with intensity at low intensities and began to saturate at about 300 GW/cm^2, and it exhibited an approximate $1/M^{1/2}$ dependence on the atomic mass of the knife edge material.

In both Beamlet and OSL we observed the phase shift in pinholes of several geometries. On-axis closure was observed in both round and square planar pinholes. Within a few nanoseconds after the onset of irradiation, a zone near the center of the aperture became opaque to the probe beam, presumably due to superposition of the plasmas from the circumference or the four edges. On-axis closure was not observed for conical pinholes or for square 4-leaf pinholes that were assembled from four separate plates distributed along the axis of the beam. The latter of these results was expected, because the plasmas from the four plates did not overlap. The lack of on-axis closure of the cone suggests that the distribution of the drive beam over the interior walls of the cone produced a slow plasma that did not reach the axis during the observation interval.

* Polymath Associates, Livermore, CA 94550

This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory, under contract number W-7405-ENG-48.

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PRELIMINARY DESIGN OF A DEFORMABLE MIRROR FOR WAVEFRONT CORRECTION OF THE "LASER MÉGAJOULE"

Pascal Jagourel, Jean-Christophe Sinquin, David Waflard (Cilas),
Pierre Joly (Commissariat à l'Energie Atomique)

The wavefront control system for the "Laser MégaJoule" requires a square 400mm side deformable mirror which will be implemented inside the laser cavity of each of the 240 beams of the facility.

The specification of such a mirror includes:

- severe constraints on shape defects over a wide range of spatial frequencies,
- laser grade polishing requirements (roughness, local defects...),
- the ability to correct for a set of large scale defects that have been estimated to be present on the uncorrected beam,
- high stability,
- insensitivity to severe electromagnetic environmental conditions,
- reliability compatible with simultaneous operation of 240 items...

The design proposed by CILAS for this deformable mirror relies on piezoelectric "bimorph" technology. This technology presents the following advantages:

- It overcomes unwanted printthrough effects usually encountered on mirrors equipped with discrete actuators placed behind the deformable plate. Nevertheless, to be able to set appropriate boundary conditions, piezoelectric actuators will be implemented outside the pupil at the edge of the mirror.
- The use of a hard piezoelectric material provides the needed linearity, reliability and insensitivity to electromagnetic field.

Last but not least, another advantage of the proposed concept relies on its ability to face production of a large number of mirrors in optimized economical conditions.

The expected performances are the results of a study phase which has involved:

- finite element calculations to provide influence functions of electrodes and actuators and derive the ability of the mirror to build the desired shapes,
- a complete analysis of polishing requirements with comparisons to results obtained previously. This analysis relies on CILAS experience in polishing and associated metrology,
- sets of measurements on stability and linearity of standard CILAS deformable mirrors based on the same "bimorph" concept: these

parameters are fundamental in the present application as opposed to more classical adaptive optics system applications where permanent real time control of the wavefront shape is available,

- a work on small mock-ups to address specific technological questions.

Simulation and analysis of ghosts images for the Megajoule Laser

H. BENARD [*], G. MATHIEU [*], N. FERRIOU [+], A. ROUSSEL [o]

[*] *OPTIS - ZE La Farlede - Rue Parmentier -*
BP 275 - 83 078 Toulon cedex 9 - FRANCE
tel : +33.(0)4.94.08.66.95 - fax : +33.(0)4..94.08.66.94
e-mail : hbenard@optis.fr

[+] *SEGIME - Be on secondment at CEA/DAM*

[o] *CEA/DAM - DLP / CSL / TO*
94 195 Villeneuve St Georges cedex - FRANCE
tel : +33.(0)1.45.95.66.73 - fax : +33.(0)1.43.86.74.07

The amplification of the Megajoule Laser will be made with a multi-pass cavity. This technical principle can generate many ghost images. In fact, beam reflections occur on lens faces, propagate in the whole system and may focus in several points. Some of these reflections can also be amplified. Furthermore, focusing points may be located near or inside optical elements and their fluence may be over the glass damage threshold. So the amplification cavity can not be realised without studying beam reflections. In consequence, *OPTIS* developed a new and specific software (Calipso) with the help and scientifical advices of the *CEA/DAM*.

Calipso is developed in two phases :

1) The aim of the first phase is to make a quick analysis of ghosts images : location, calculation of the fluence in hot spots and on the faces of the nearest optical elements. For example, the amplification cavity is made of around 340 surfaces. So, at the first order, we find 57 630 images potentially dangerous. At the second and third order this number grows respectively to 13 043 590 and 2 767 690 355... The quick pre-treatment is based on an generalised paraxial analysis, developed by both *CEA* and *OPTIS*. This calculation takes into account the elements aberrations, the factor of amplification, the factor of recovering of pencil beams... The results of the first phase tell to the user which reflections are dangerous, and what are approximately their fluence and location.

2) The aim of the second phase is to prepare essential parameters for a simulation with Laserpro [(1)]. This module is based on an original method : plane waves are emitted by a Monte-Carlo technique. Then they are propagated through the optical chain and are integrated in the Fourier domain. An inverse Fourier

Transform gives the complex amplitude in the analysis plane. As we can see, we have developed a rigorous coherent propagation which takes into account not only phase distribution but also amplitude distribution. It yields to accurate results for both location and fluence calculation of hot spots. It is also possible to move the observation plane provided it remains in an homogeneous medium. Thus, we can obtain a curve of the maximum fluence along the propagation axis and determine irradiance maps on the nearest optical elements.

In the article, we will present the physical concepts behind Calipso. In particular, we will give a full explanation of the coherent propagation model.

(1) Laserpro is a software developed by *OPTIS*.

Laser-induced damage of silica glasses at 1064 nm and it's higher harmonics

K.Yoshida
Department of Electronic Engineering, Osaka Institute of Technology
5-16-1, Ohmiya, Asahi-ku, Osaka 535-8585, Japan

N.Kuzuu
Depaetment of Applied Physics, Fukui University
3-9-1, Bunkyo, Fukui 910-8507, Japan

T.Jitsuno, H.Yoshida
Institute of Laser Engineering, Osaka University
2-6, Yamada-oka, Osaka 565-0871, Japan

Vitereous silica (v-SiO_2) has high optical transmission in wide wavelength region from vacuum ultraviolet (UV) to near infrared (NIR), and low thermal expansion coefficient compared to multi-component optical glasses. Recently, this materials are used for industrial excimer laser such as semiconductor lithography steppers.

The v-SiO_2 can be divided into two groups ; synthetic fused silica (SFS) and fused guartz (FQ) produced by melting natural quartz powder. We studied the wavelength dependence of the laser-induced damage threshold of silica glasses at 1064, 532, 355, and 266 nm, and obtained the following results. (1) At 1064 nm, the laser-induced damage threshold (LIDT) for all samples are the same within the experimental errors. (2) The LIDT is proportional to the 0.43-th power of wavelength in the range of 1064-355 nm for SFS. (3) The LIDT values of FQ at 532 and 355 nm are slightly less than those for SFSs. This might be related to the absorption induced at these wavelengths. This phenomenon is the same as the occurrence of absorption at wavelength shorter than 600 nm in the cases of X-ray and KrF-laser irradiation. (4) The LIDT of SFS containing Cl_2 and no OH at 355 nm is between that of FQ and those of the other SFSs ; it might be caused by the aabsorption of Cl_2 molecules in the silica glass. (5) At 266 nm, the LIDT value is considerably lower than the extrapolated value from "the 0.43-th power wavelength dependence". This is quite different mechanism from that at longer wavelengths. At this wavelength, damage occurs through two-photon absorption process, but not at longer wavelengths.

Directional dependence of damage threshold of KDP crystal with polarized laser light

Hidetsugu Yoshida, Masashi Yoshimura*, Takahisa Jitsuno, Hisanori Fujita, Masahiro Nakatsuka, Yusuke Mori* and Takatomo Sasaki*

Institute of Laser Engineering, Osaka University
2-6 Yamada-oka, Suita, Osaka 565, Japan
Phone +81-6-879-8761, Fax +81-6-877-0900
e-mail:hideyo@ile.osaka-u.ac.jp

* Department of Electric Engineering, Osaka University
2-1 Yamada-oka, Suita, Osaka 565, Japan
Phone +81-6-879-7707, Fax +81-6-879-7708

The laser fusion facility required a large single crystal of KH_2PO_4(KDP) for frequency conversion and as a part of large aperture optical switch(Pockells Cell). The KDP crystal has a lower laser damage threshold than other optical materials.

The bulk damage threshold of KDP single crystals were determined with various laser irradiations and polarization directions at wavelength of 0.266 μm, 0.355 μm, 0.532 μm, and 1.064 μm. The damage threshold with various laser irradiations and polarizations were different. For example, the damage thresholds of 18.5 -24 J/cm^2 in the direction of c-axis were about two times higher than that of 11.5 -13 J/cm^2 in the a-axis delivering a 1.1 ns single pulse at wavelength 1.064 μm. It is suggested that this results is due to the impurities(inorganic, organic, water) or structural deffects in crystal striations.

Laser-induced damage of optical coatings grown with surface chemical reaction

Shin-ichi Zaitsu, Shinji Motokoshi*, Takahisa Jitsuno and Tatsuhiko Yamanaka

Institute of Laser Engineering, Osaka University, 2-6 Yamada-oka, Suita, Osaka 565-0871, Japan
*Institute for Laser Technology, 2-6 Yamada-oka, Suita, Osaka 565-0871, Japan
Phone: +81-6-879-8762 FAX: +81-6-877-4799 E-mail: zaitsu@ile.osaka-u.ac.jp

High-power laser systems used for inertial confinement fusion are required to operate over long periods without degradation in performance. Particularly, optical multilayer coatings in these laser systems are prone to damage by intense laser irradiation. Therefore, the improvement of the damage thresholds of dielectric multilayer coatings, such as a polarizer, is essential for the development of high-power laser systems. In order to develop optical coatings with high resistance to laser-induced damage, we have been investigated the thin films grown by surface chemical reactions.

Controlled growth of thin films by surface chemical reactions was developed to fabricate various compound materials.[1,2] This growth method allows the controlled growth of films with high uniformity of thickness and low defect density. The principle is based on sequential exposures of the substrate surface to different reactants. The atomic-scale growth of films is achieved by chemical reaction and adsorption on the surface. In this growth method, the surface chemisorbs a monolayer of the precursor due to the saturation of absorbing moleculars. This surface reaction allows precise control of thickness and forms uniform films on large areas. In this work, titanium dioxide(TiO_2) films grown by using tetrachlorotitanium($TiCl_4$) and H_2O were investigated.

The proportional relationship between the thickness and the number of cycles was confirmed The thickness can be controlled only by the number of reaction cycles. The growth rate was approximately 0.04 nm/cycle at the temperature of 200℃. The distribution of thickness was within 1% over 24cm in diameter on the surface. The damage threshold of TiO_2 films decreased at higher the growth temperature. The film at the growth temperature of 25℃ had a damage threshold of 3.6 J/cm^2 for 1-ns, 1.06-μm laser pulse. The experimental results on Al_2O_3 films will be also presented.

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Design on a new technique for alleviating thermal dephasing of NLO crystal

Y. K. Yap*, K. Deki, Y. Kagebayashi, M. Horiguchi, Y. Mori*, and T. Sasaki*

*Department of Electrical Engineering, Osaka University
2-1 Yamadaoka, Suita, Osaka 565, Japan.
TEL: +81 -6-879-7707
FAX: +81 -6-879-7708
email: yap@ssk.pwr.eng.osaka-u.ac.jp

Tsukuba R&D Laboratory, USHIO Inc.
5-2-4 Tokodai, Tsukuba, Ibaraki 300-26, Japan.

Abstract

High power solid-state laser is highly demanding due to its compactness and convenient operation procedure. For the demand of higher photon energy, wavelength of solid-sate laser at 1 μm region is usually convert to visible and ultraviolet region by using nonlinear optical (NLO) crystals. However, due to intrinsic absorption of NLO material, a non-uniform temperature profile formed inside the crystal, both traverse and parallel to the direction of laser beams. Non-uniform refractive index is then induced and results in a deviation of phase velocities among the involved laser beams. Such thermal induced phase mismatch (TIPM) phenomenon is usually called thermal dephasing.

Many techniques have been proposed for resolving thermal dephasing in NLO crystal. Most of these techniques are aimed for promoting heat dissipation from NLO crystal by means of increasing gas exploring crystal area as referred to the overall crystal volume.

We have developed a simple technique for alleviating thermal dephasing of NLO crystal. This is based on a totally new mechanism that we called temperature profile compensation (TPC). This technique involved no modification on the dimension of NLO crystal, no moving laser beam and without mobile optical component. We simply heat up a CLBO crystal [1] and followed by gas cooling at the laser output surface. Conversion efficiency from a laser wavelength of 532 nm to 266 nm was improved by 2.3 times as compared to that without cooling. An average UV output power of 10.6 W was generated at 100 Hz, with a conversion efficiency of 52 % from the green. This result is more effective than the best result (39 % conversion efficiency) optimized at room temperature [2]. A stability as high as 98 ± 2 % was obtained from the 10.6 W radiation. Design consideration of this cooling technique based on the TPC concept will be discussed.

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Noncritically phase-matched third harmonic generation of Nd:YAG laser in gadolinium yttrium calcium oxyborate $Gd_xY_{1-x}Ca_4O(BO_3)_3$

M. Yoshimura, T. Kobayashi, H. Furuya, K. Murase, Y. Mori, and T. Sasaki

Department of Electrical Engineering, Osaka University,
2-1 Yamada-oka, Suita, Osaka 565-0871, Japan;
Phone / Fax: +81-6-879-7707 / 7708
E-mail: yoshimura@ssk.pwr.eng.osaka-u.ac.jp

In recent years, visible and UV lasers have been in demand for many applications including industrial, medical and entertainment applications. Frequency conversion of solid-state lasers by nonlinear optical (NLO) crystals has become the most available method to obtain shorter wavelength lasers with high beam stability, low cost and compactness. For NLO crystals, KH_2PO_4 (KDP), $KTiOPO_4$(KTP), LiB_3O_5 (LBO), ß-BaB_2O_4 (BBO) and $CsLiB_6O_{10}$ (CLBO) and so on, have been developed so far. Much effort has been continuously spent on developing the new NLO crystals with large nonlinear coefficient, ease in growth, and high mechanical and chemical stability. Aka *et al.* reported that $GdCa_4O(BO_3)_3$ (GdCOB) is an excellent candidate for practical NLO crystal for doubling the Nd:YAG fundamental, because of ease in growth, and its stable chemical and mechanical properties [1]. The Sellmeier equations, however, predict the limit of phase-matching (PM) wavelength to be 840 nm due to the small birefringence of 0.033 at 1064 nm. Further efforts are necessary for developing the GdCOB families with larger birefringence in order to generate shorter wavelength.

In 1997, we have found that replacement of Gd by Y can lead to an increase in the optical birefringence from 0.033 to 0.041 [2]. Therefore, the limit of PM wavelength can be shortened to 720 nm. YCOB can also generate the third harmonic of Nd:YAG fundamental, whereas not by GdCOB. Recently, we have succeeded to develop $Gd_xY_{1-x}Ca_4O(BO_3)_3$ (Gd_xY_{1-x}COB) crystal in order to control optical birefringence. This is important to achieve noncritical phase-matching (NCPM) condition which can lead a significant improvement of frequency conversion efficiency. The crystals without cracks and bubbles could be grown by the Czochralski method at a pulling rate of 3.0 mm/h and a rotation rate of 30 rpm. Gd_xY_{1-x}COB crystals had an uniformity of crystal composition along with growth direction so these crystals confirmed a substitutional solid solution of Gd_xY_{1-x}COB. A variation in the mole fraction of Gd in Gd_xY_{1-x}COB leads a wavelength for NCPM second harmonic generation lying within the range of 830-970 nm at room temperature. Furthermore, we have generated NCPM third harmonic generation of Nd:YAG fundamental in $Gd_{0.24}Y_{0.76}$COB.

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Design of Kinoform Phase Plate for Irradiating Spherical Target

Kouji Tsubakimoto, Noriaki Miyanaga, Motoyuki Okuo, Keiichi Sueda, and Masahiro Nakatsuka

Institute of Laser Engineering, Osaka University
2-6 Yamadaoka, Suita, Osaka 565-0871, Japan
Phone: 81-6-879-8762, Fax: 81-6-877-4799
e-mail: tsubaki@ile.osaka-u.ac.jp

The random phase plate (RPP) is useful to remove nonuniformities in a far field pattern. And, lower spatial frequency components of the irradiation nonuniformity on the spherical target can be suppressed by optimizing a segment size, a focal number and a defocusing condition of an irradiation scheme. But, an energy deposition efficiency of optimized RPP is about 64 %. While, a kinoform phase plate (KPP)[1] can produce an optimum envelope profile, and an energy efficiency is higher than that of the RPP.

The KPP has two problems in its fabrication and design. The one is the common problem of phase shift masks. A phase shift error of the mask causes a center spike into a far field pattern. So, it is a good choice that the KPP is used in a near-far field region. The intensity of the center spike decreases at the quasi-far field. The another problem is the difference between an irradiation plane and a design plane. The laser light directly irradiates the spherical target. While, the KPP is designed at a plane surface. It may be difficult that the KPP keeps the design pattern on the spherical target surface.

We describe the design and the control capacities of the irradiation profile. To investigate the effects of the defocusing, we designed the KPP in the quasi-far field. And we calculated the complex amplitude distribution on the spherical surface for estimate the irradiation uniformity.

The KPP is designed by the numerical method with the phase reconstruction algorithm. It is the blind deconvolution (BD) method[2] using fast Fourier transform(FFT). We use the Fresnel transform to calculate the quasi-far field pattern. The Fresnel diffraction pattern can be numerically calculated by using the FFT. We added the dispersed phase factor to the complex amplitude distribution of input pattern.

The KPP can be designed at quasi-far field. The controllability, however, is still poor. When the KPP is designed according to the flat top profile, the center of the reconstructed pattern is depressed, yielding the lack of the intensity in the center area. It is desirable that the KPP is designed in the defocal position less than 750μm on GekkoXII, and the KPP permits the almost sane irradiation profile if the tangential plane is less than 200μm. This suggests that the control of the irradiation profile can be achieved for the target of 500 μm diameter.

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Alignment control of liquid crystal molecules by use of photoisomerization

Keiichi Sueda, Kouji Tsubakimoto, Noriaki Miyanaga, and Masanori Nakatsuka

Institute of Laser Engineering, Osaka University
2-6, Yamada-oka, Suita, Osaka 565-0871, Japan
Phone:+81-6-879-8762 FAX:+81-6-877-4799

In the direct drive laser fusion, the smoothness of the intensity pattern of each beam has been improved by the use of the random phase plate (RPP). The RPP reduces the far-field nonuniformity caused by the spatial phase and intensity distributions in the near field. However a laser beam through the RPP is divided into many small beamlets and then piled up at a target plane with a focusing lens. An intensity distribution of the whole beam in a far field region consists of speckles due to random interference. Although the intensity envelope is relatively uniform, the nonuniformity in the spatial high frequency components causes an imprinting on the target surface. We are investigating the polarization control for the instantaneous speckle smoothing to overcome this problems.

To smooth the speckles using polarization control, we need a laser beam consists of two components of which polarization direction are orthogonal to each other. This is realizable by installing polarization rotator array. Such a polarization control plate (PCP) is composed, in principle, by many small half-waveplates.

A laser beam divided into many small perpendicularly polarized beamlets through the PCP creates independent two speckle patterns, and they are piled up instantaneously. In consequence, the speckle contrast is reduced by a factor of 30%. In optimizing PCP, the element size must be the same order of the coherence area of the partially coherent light. Therefore we use a half wave plate array of segmented nematic liquid crystal. The polarization property of the PCP depends on the alignment control method of liquid crystal. A rubbing method was previously adopted. But there remains a problem in the fabrication process such as substrate pollution and one can not align liquid crystal in the optional pattern.

Therefore we aim at an establishment of nonrubbing method and tried an alignment control of liquid crystal using photoisomerization induced by polarized UV laser. The glass substrate of liquid crystal cell, which is coated with polyvinylalcohol doped with methyl orange, was illuminated with a linearly polarized third harmonic of Nd:YAG laser. We confirmed an alignment of liquid crystal within the illuminated region according to the poralization direction of this UV laser. This PCP reduced the contrast of speckle pattern caused by RPP by a factor of 30%.

High-Peak-power 2D Laser Diode Arrays for Pumping the Laser Fusion Driver.

H.Kan, T.Kanzaki, H.Miyajima, M.Miyamoto, Y.Itoh, K.Matsui, T.Hiruma
T.Jitsuno*, M.Yamanaka*, Y.Izawa* and S.Nakai*

Hamamatsu Photonics K.K.
*Osaka University

Abstract

High peak power, good focus, high efficiency and long life 2-D laser diode arrays are very important for exciting solid state lasers.

The LD structures were grown by MOCVD method. After ohmic contact processing, the wafers were cleaved into 1cm-long LD bars. The LD bars were bonded on to a heat sink. We have made 2-D LD arrays by staking 1-D LD bars layer by layer.

Fig.1 shows the quasi-CW (QCW) peak output power against current for a 3×25-stack LD array (total 75 bars). 7.5kW peak power was obtained. The output power density is 2.5kW/cm2.

Fig.2 shows the outlook of the water cooled quasi-CW 7.5kW LD array module.

Fig.3 shows duty cycle dependence of the I-L characteristics of the 8-stack 2-D LD arrays. Over 400W peak power under QCW operation (200μ sec, 1kHz, duty cycle 20%) was achieved.

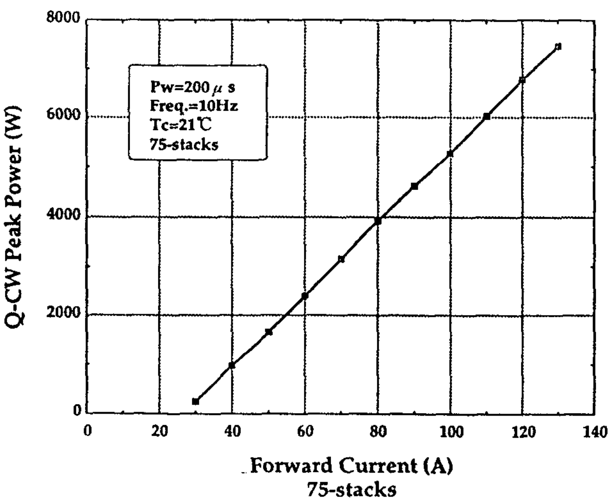

Fig.1 QCW output power as a function of current for 75-stacks LD arrays.

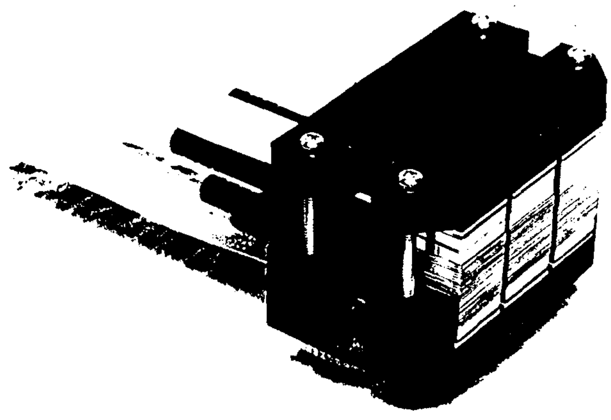

Fig.2 The outlook of water cooled QCW 7.5kW LD array nodule (25-stack×3 LD arrays) (operation condition : 200μ sec, 10Hz)

H.K. Email:kan@crl.hpk.co.jp FAX:053-585-0673 TEL:053 586 7111

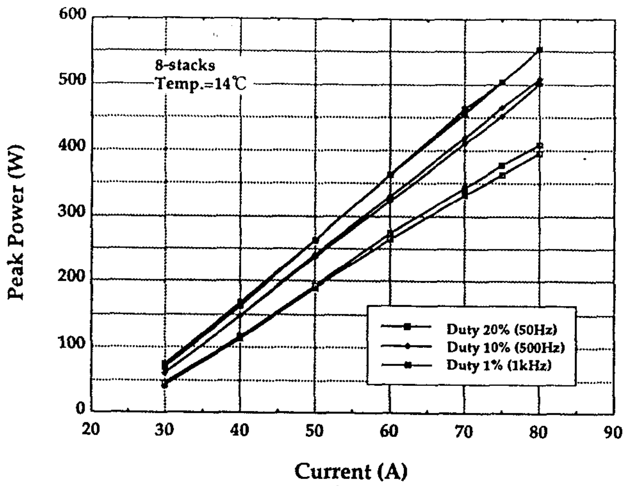

Fig.3 The duty cycle dependence of the I-L characteristics of the 8-stack 2-D LD arrays.

Summary

We have developed 0.8～0.9 μ m band high power 2-D laser diode (LD) arrays for pumping solid state lasers and evaluated their characteristics. We are now developing laser diodes which are more suitable for pumping solid state lasers.

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Development of LD Pumped 10J x 10Hz Nd:Glass Slab Laser

H. Matsui, N. Eguchi, T. Kanabe, T. Jitsuno, N. Hiura, H. Furukawa,*
M. Yamanaka, M. Nakatsuka, Y. Izawa, S. Nakai,
T. Kanzaki+, H. Miyajima+, M. Miyamoto+ and H. Kan+

Institute of Laser Engineering, Osaka University, 2-6,
Yamada-oka, Suita, Osaka 565-0871, Japan
TEL: +81-6-879-8738
FAX: +81-6-877-4799
E-mail: hmatsui@ile.osaka-u.ac.jp

*Institute for Laser Technology, 2-6, Yamada-oka, Suita, Osaka 565-0871, Japan

+Central Research Laboratory, HAMAMATSU PHOTONICS K.K., 5000,
Hirakuchi, Hamakita, Shizuoka 434-8601, Japan

We have proposed and designed a diode-pumped solid state laser (DPSSL) driver for inertial fusion energy (IFE) which consists of water-cooled zig-zag path Nd:glass slab amplifiers. A driver module was designed under the several operational constraints and has 10 kJ total output energy at 351 nm and operates at 12 Hz with 10.4% overall efficiency. The laser driver producing 4 MJ blue output for IFE will consist of 400 modules. To confirm the design, we are developing a small scale DPSSL module of 10J x 10Hz laser output at 1053nm.

The IFE power plant KOYO has the basic design specifications of 4 MJ output at 351 nm and 12 Hz repetition rate. For the laser gain medium, we have adopted the glass host which can be produced in large sizes with good optical quality. The HAP-4 glass (HOYA) has the appropriate material parameters for designing a high power and repetitively operating laser system because of higher thermal shock parameter of 140 W/m. The slab dimensions were determined under the several operational constraints such as thermal shock fracture, optical damage, parasitic oscillation, ASE and B-integral, Zig-zag path slab has an advantage that the laser beam does not pass through the cooling medium as it propagates by means of total internal reflections. Using this advantage, the slab is cooled on both sides with flowing water having high cooling capability.

A driver module for the IFE consists of 15 beamlets and each beamlet has a double 4-pass system as it plays the role of both pre-amplifier (4-pass system) and main amplifier (4-pass system), which results in a compact system. Each beamlet is amplified from 10 μ J input energy to 700 J of blue output energy. The module has, therefore, 10 kJ total blue output energy, and operates at 12 Hz with 10.4% overall efficiency. So, the designed DPSSL driver producing

4MJ blue output for IFE consists of 400 modules, each composed of water-cooled zig-zag path Nd:glass slab amplifiers.

As a first step of a driver module development for the IFE, we are developing a small scale DPSSL module which has 10J x 10Hz laser output at 1053 nm. The module is the smallest size to confirm the design of driver module. AlGaAs laser diodes (HAMAMATSU) to pump the amplifier of the module system have 200kW total peak power and 2.5kW/cm^2 peak power density at duty 0.2%. The zig-zag slab of HAP-4 glass (HOYA) has the size of 523(L) x 119(w) x 20(t), which also matches to 100J x 10Hz module. We will demonstrate the 10J x 10Hz laser output at 1053nm.

We are also developing a simulation code of thermal effects in a zig-zag slab to design the driver module for the IFE in detail. It is important to know the simulation results on the thermal effects such as thermal aberration, thermal lensing and thermal birefriengence, because it will be incorporated to a datum base for the module design for IFE.

A PETAWATT CLASS LASER SYSTEM FOR LASER-MATTER INTERACTIONS

D. M. Pennington, M. D. Perry, J. A. Britten, C. G. Brown, S. Herman, M. W. Kartz, J. L. Miller, B. C. Stuart, G. Tietbohl, V. Yanovsky
Lawrence Livermore National Laboratory, Box 808, L-439 Livermore, CA 94550
Telephone: (510) 423-9234, Telefax: (510) 422-5537

ABSTRACT

The Petawatt Laser at LLNL is a Ti:sapphire/Nd:Glass laser system which produces > 1.25 PW peak power. An irradiance of 10^{20} - 10^{21} W/cm^2 is achieved utilizing an on-axis parabolic mirror, with adaptive optic wavefront correction. The Petawatt Laser Project was initiated to develop the capability to test the fast ignitor concept[1] for inertial confinement fusion (ICF), and to provide a unique capability in high energy density physics. This laser produces near kJ pulses with a pulse duration adjustable between 0.5 and 20 ps, using chirped pulse amplification with 94-cm compression gratings. Only the central 80% of the disk amplifiers is utilized in order to maintain a good wavefront. Near diffraction limited beam quality is achieved at 10 Hz with the use of a 37-actuator deformable mirror wavefront control system. The corrected wavefront at the output of the laser has ~ 0.25 waves of distortion peak-to-valley and ~ 0.10 waves rms, producing a near diffraction limited focal spot. Experiments are currently in progress to determine the wavefront at full power, using the mirror to correct for static, thermal and pump-induced aberrations in the amplifier chain.

Target experiments with petawatt pulses are currently possible in an independent target chamber. Focusing the beam is accomplished using an on-axis parabolic mirror protected by a debris shield for pulses as short as 5 ps. For shorter pulses, the B-integral in the debris shield is prohibitively large, so focusing is accomplished using the parabolic mirror in conjunction with a secondary "plasma" mirror.[2] The high power focused irradiance is measured by an equivalent focal plane optical imaging system, as well as by an x-ray pinhole camera at target chamber center. A number of target experiments have now been performed with the Petawatt laser system, providing the first glimpse into this new realm of laser-matter interactions.

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This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract No. W-7405-ENG-48

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CREATING OF THE EXPERIMENTAL SETUP WITH OUTPUT ENERGY 5 J AND CONTROLLED PULSE SHAPE

Rukavishnikov Nikolay.N., Sharov Oleg.A., Sukharev Stanislav.A.

Russian Federal Nuclear Center - Institute of Experimental Physics (VNIIEF)
37, pr.Mira, Sarov, Nizhni Novgorod reg., Russia, 607190
Phone: (83130)-4-56-46, Fax: (83130)-5-45-65
E-mail: SUKHAREV@otd.13.vniief.ru

Results of the master oscillator, pulse forming and preamplifier system for elaboration of the created in RFNC-VNIIEF high power Nd-phosphate glass facility "Lutch - Iskra-6" front-end system was presented. Single-mode monopulsed Nd laser ($\lambda = 1.05\ \mu m$) with output energy ≈ 5 J, diffraction-limited beam, controlled pulse duration and temporal shape ($\tau_{prepulse} \approx 5$-$10$ ns, $\tau_{0.5} \approx 3$-5 ns, controlled peak-to-foot contrast ratio $I_{peak}/I_{foot} \approx 5$-$100$) was created.

Transverse SRS in KDP, and DKDP crystals.

Novikov V.N., Belkov S.A., Buiko S.A., Voronich I.N., Efimov D.G., Zaretsky A.I., Kochemasov G.G., Kravchenko A.G., Kulikov S.M., Lebedev V.A., Okutin G.P., Rukavishnikov N.N., Sukharev S.A.

Russian Federal Nuclear Center (VNIIEF)
607190, Sarov, Nizhni Novgorod Region, Russia
Fax : (83130) 456-46, Phone : (83130) 458-93, e-mail : novikov@otd13.vniief.ru

Abstract

On the third harmonic of iodine laser ISKRA-4 (λ=438 nm) the measurements of gain values of transverse SRS (TSRS) radiation in the frequency converter crystals (KDP, KD*P) grown following the traditional and rapid-growth technology have been carried out.

Measurements of gain coefficient were conducted at TSRS excitation in small sized ($1{,}5\times1{,}5\times1{,}5$ cm^3) crystals, placed into the cavity with plane mirrors /1/. Pumping radiation was focused by cylindrical lens. In the cavity TSRS was excited in parallel with cylindrical lens axis and in transverse direction about pumping. In experiments pumping radiation power and TSRS radiation pulse shape have been recorded.

Determination of gain coefficient (g) was carried out by minimizing the functional :

$$F(g,t_{\max}) = \int\left(\left(\frac{P_S(t)}{P_{S\max}}\right)_{\exp} - \exp a\, g \int_{t_{\max}}^{t}\left(P_L(t') - P_L(t_{\max})\right)\cdot dt'\right)^2 dt,\quad a = \frac{c}{n}\cdot\frac{L}{d}$$

varying g and t_{max} - the time of reaching TSRS radiation power maximum in calculated dependence (the second term in brackets). Here $(P_S(t)/P_{S\,max})_{exp}$ is experimentally obtained Stokes pulse shape normalized on maximum value; $P_L(t)$ and $P_L(t_{max})$ are pumping radiation power at present instant of time t and at instant $t=t_{max}$; n - refraction index; L - cavity length, d - effective thickness of crystal radiation region. The value of t_{max} was varied within the obtained TSRS pulse top.

At the g measurements in crystals pumping wave was ordinary; the pumping and scattered wave vectors and the crystal optical axis were coplanar. As a result we have obtained the following Transverse SRS radiation gain values :

- in the the traditionally grown KDP and KD*P crystals the measured g values are 0.29±0.03 cm/GW and 0.15±0.03 cm/GW correspondingly;
- in the rapid grown KDP crystal the measured g value is 0.6±0.1 cm/GW.

For KDP and KD*P, grown following the traditional slow-growth technology, our results and the results of work /2/ are in a good agreement when a frequency dependence of gain coefficient and geometry of experiments are taken into account.

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Development of Practical Damage-Mapping and Inspection Systems *

F. Rainer, R. T. Jennings, J. F. Kimmons, S. M. Maricle,
R. P. Mouser, S. Schwartz, C. L. Weinzapfel
Lawrence Livermore National Laboratory
P. O. Box 5508, L-487, Livermore, CA 94551-9900
Tel: (925) 422-4376, Fax: (925) 422-1210, email: rainer1@llnl.gov

We have developed and are continuing to refine semi-automated technology for the detection and inspection of surface and bulk defects and damage in large laser optics. Different manifestations of the DAMOCLES system (Damage and Artifact Mapping Of Coherent-Laser-Exposed Substrates) provide an effective means of being able to detect, map and characterize surface or bulk defects which may become precursors of massive damage in an optic if subjected to high-fluence laser irradiation. Subsequent morphology and evolution of damage due to laser irradiation can be tracked. The strength of the Damocles is that it allows for immediate visual observation of defects of the entire optic, which can range up to 1-meter dimensions, while also being able to provide digital maps and magnified images of the defects with resolutions of < 5 μm.

The full implementation of Damocles requires a three-step process. First, white light is injected through the edges of the optic into the bulk of the material by a series of fiber-optic, light lines around the optic perimeter. This provides an efficient means of coupling the greatest amount of light into the bulk volume with at least one pass across the optic because of total internal reflection. Smaller fiber-optic bundles can be used for small or round optics; grazing illumination is employed if the objective is to detect surface contamination. Defects which propagate into the substrate (pits, scratches, inclusions, bubbles) and surface contaminants (dust, cleaning flaws) scatter the white light for visible observation. Second, a mega-pixel, digital camera is used to photograph the entire optic so that the highlighted defects can be mapped with discrete digital addresses. Third, after obtaining automated x-y coordinates of these defects, a long working-distance microscope is used to generate magnified digital images of the defects along with their z-coordinates into the bulk of the substrate.

We have exploited the versatility of Damocles for a variety of applications and its success is evidenced by its acceptance as a definitive diagnostic tool by the commercial optics vendors that are supplying the large-scale optics for the National Ignition Facility (NIF) currently being constructed at the Lawrence Livermore National Laboratory (LLNL). Optical-finishing vendors are gearing up to employ Damocles to study the effects of polishing and etching processes to raise surface damage thresholds. The effects of resultant artifacts such as pits and scratches are studied both before and after laser irradiation. On-line inspection of bulk flaws such as inclusions or bubbles are being planned by fabricators of fused-silica boules and frequency-conversion crystals. Accurate recording of the evolution of damage after one or more laser shots as well as correspondence of damage from one optic to the next in a laser chain is being implemented at LLNL. The light-line technique has now become the default vendor inspection system for detecting damage-causing platinum inclusions in neodymium-doped laser slabs. In addition, defects in edge claddings can readily be highlighted to preclude potential delaminations under high temperature flashlamp and laser loading. Surface contaminants can be quantified by the same mapping techniques employing grazing illumination.

* This work was performed under the auspices of the U. S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-ENG-48.

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TH2A-5

Thermal Recovery of the NIF Amplifiers

S. Sutton, A. Erlandson, R. London, K. Manes, C. Marshall,
C. Petty, R. Pierce, L. Smith, and L. Zapata

Lawrence Livermore National Laboratory
P.O. Box 808, L-441
Livermore, CA 94550

J. Beullier and B. Bicrel

CEA Limeil-Valenton, DRIF/DLP
94195 Villeneuve St-Georges, France

Abstract

With approximately 99% of the electrical energy supplied to the NIF appearing as heat in the amplifiers, thermal recovery of the NIF system has been a major topic of study for the past two years. A design requirement of 8 hours between shots, with a goal of 4 hours, has necessitated a detailed computational and experimental investigation of heat transfer within the NIF amplifiers, and the residual optical distortions associated with temperature imbalances in the system.

Residual optical distortions are grouped into two discrete categories: (1) distortions associated with residual temperature gradients in the laser slabs, and (2) distortions associated with buoyantly driven convective currents in the amplifier cavity and beam-tube regions. The present understanding of thermal recovery requirements, which provide the design goals for NIF amplifier recovery, is discussed in terms of allowable system temperature differences and gradients.

Thermal recovery of the amplifiers is achieved by cooling the flashlamps and blastshields with a turbulent gas flow. The cooled blastshields then serve as a cold boundary to radiatively extract the residual heat deposited in the slabs and edge claddings. The NIF baseline cooling conditions are ambient temperature gas flowing at a rate of 20 CFM per flashlamp. Advanced concepts, such as the use of slightly chilled gas to accelerate some aspects of recovery, are addressed.

To quantify recovery rates of the amplifiers, experiments and a multi-step analysis approach are used. First, detailed finite element heat transfer calculations are performed that included convective heat transfer in the flashlamp cassettes, natural convection in the amplifier cavities, and radiative heat transfer within the amplifier. This is followed by calculation of the temperature gradient driven slab stresses and distortions using finite element analysis tools. The final step in the sequence is the prediction of the resulting

optical distortions in the laser slabs, calculated using a ray-trace technique. The calculation results are extensively benchmarked against AMLAB temperature and optical distortion measurements, thus allowing a quantitative prediction of NIF thermal recovery.

These results indicate that the NIF requirement of 7 hour thermal recovery can be achieved with slightly chilled cooling gas. Additionally, it is shown that a more aggressive reduction in the flashlamp cassette cooling gas temperature significantly accelerates recovery of the slab from the average temperature standpoint, thus providing faster gas distortion recovery. The chilled-gas approach, however, but does little to accelerate the relaxation of temperature gradients across the slab aperture.

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PROGRESS IN LARGE DIMENSIONS TRANSPORT MIRROR AND POLARIZORS WITH HIGH LASER INDUCED DAMAGE THRESHOLD FOR THE LIL AND LMJ

H. Leplan B. Pinot
REOSC
14, rue Paul Dautier
78141 Velizy Villacoublay - France
Tel: (33) 01.69.89.76.88 Fax: (33) 01.69.89.76.20

O. Lam* A. Fornier** J. Neauport* A. Roussel**
*ALTRAN TECHNOLOGIES
58 bd Gouvion ST CYR
75858 Paris cedex 17 - France
**CEA - Centre d'Etudes de Limeil Valenton
94195 Villeneuve Saint Georges Cédex - France

Multilayers coatings manufacturing from hafnia and silica sources by reactive electron beam deposition are being developed conjointly by REOSC and CEA Limeil-Valenton for the production of the large dimensions mirrors and polarizors required for the LIL and LMJ projects.

During the last two years, a number of parameters have been investigated in order to reach the LIL and LMJ fluence specifications for the transport mirrors (> 25 J/cm^2) and the large polarizors (>12 J/cm^2 in P polarization) : substrate cleaning, deposition conditions (oxygen partial pressure, electron gun types and parameters), evaporation starting material (vendors, packaging...), thickness of the silica overcoat layer, laser and annealing conditioning... In this paper, the most significant results obtained during these studies will be presented. It will be shown that characterized on small witness samples, the LITD specifications are reached without laser conditioning for the transport mirrors but required a laser conditioning step for the polarizors in P polarization.

Apart from the previous parametrical studies realized on ϕ50 witness samples, 20 large dimensions mirrors (620*440 mm^2) and 2 large polarizors (710*440 mm^2) were also coated in order to evaluate the coating yield for the LIL and LMJ production. Results of the characterization of this large dimensions optics will also be summarized (in terms of flatness, spectral uniformity and LIDT characterized during full scale laser irradiation experiments on PHEBUS and BEAMLET).

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REOSC EXPERTISE IN HIGH ENERGY LASERS OPTICS MANUFACTURING

Franccois Houbre, Guillaume Blanchard*
André Roussel, Geneviève Chabassier, Jacky Duchesne**

*REOSC, avenue de la Tour Maury, 91280 Saint Pierre du Perray, France
Tel: 33 1 69 89 76 81 Fax: 33 1 69 89 72 20

**CEA-LV, 94195 Villeneuve Saint Georges CEDEX, France
Tel: 33 1 45 95 60 56 Fax: 33 1 43 86 74 07

Fabrication of the large optical components for the Megajoule laser is a huge challenge for the European industrial companies involved in this program.

It's the first time that we have to produce a great number of large square or rectangular optics, with tight wavefront specifications at very low costs, compared with those that are currently needed for such optics.

In order to reach the required specifications while decreasing the finishing costs, CEA and REOSC have worked together, improving finishing machines, wavefront measurement methods and devices, and finishing processes.

In collaboration with CEA, REOSC got a 20 years experience in big size and high energy laser optics polishing and coating. Based on this experience, some one scale optics (amplifier slabs, filtering lenses, polarizers, mirrors) have been finished during preliminary studies for the LMJ project.

We show a brief analysis of measurement results on these pieces and compare them with required specifications. Improvement in interferometric test methods and PSD criteria calculation will be set out.

We show how Computer Controlled Polishing and Ion Beam Figuring could be used for aspherical optics fabrication, and we present the MEGAPOL 1 program, the new planetary machine for LIL plano optics finishing.

At last, we report some experimental results on 3ω laser damage threshold managed in collaboration with LLNL and we present our work in finishing a one scale focusing lens.

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TP

CONSTRUCTION OF THE PROTOTYPE OF OPTICAL SYSTEM FOR MEASUREMENT OF SMALL WAVEFRONT DISTORTIONS OF LASER RADIATION IN OPTICAL ELEMENTS

Stanislav Kulikov

Russian Federal Nuclear Center - Institute of Experimental Physics
Sarov, Nizhny Novgorod region, Russia, 607190
Phone: 831 30 4 58 93, Fax: 831 30 5 45 65, E-mail: kulikov@vniief.ru

The purpose of the project consists in creation of technology of measurement extreme small wavefront distortions, arising at passage radiation through transparent components of optical devices.

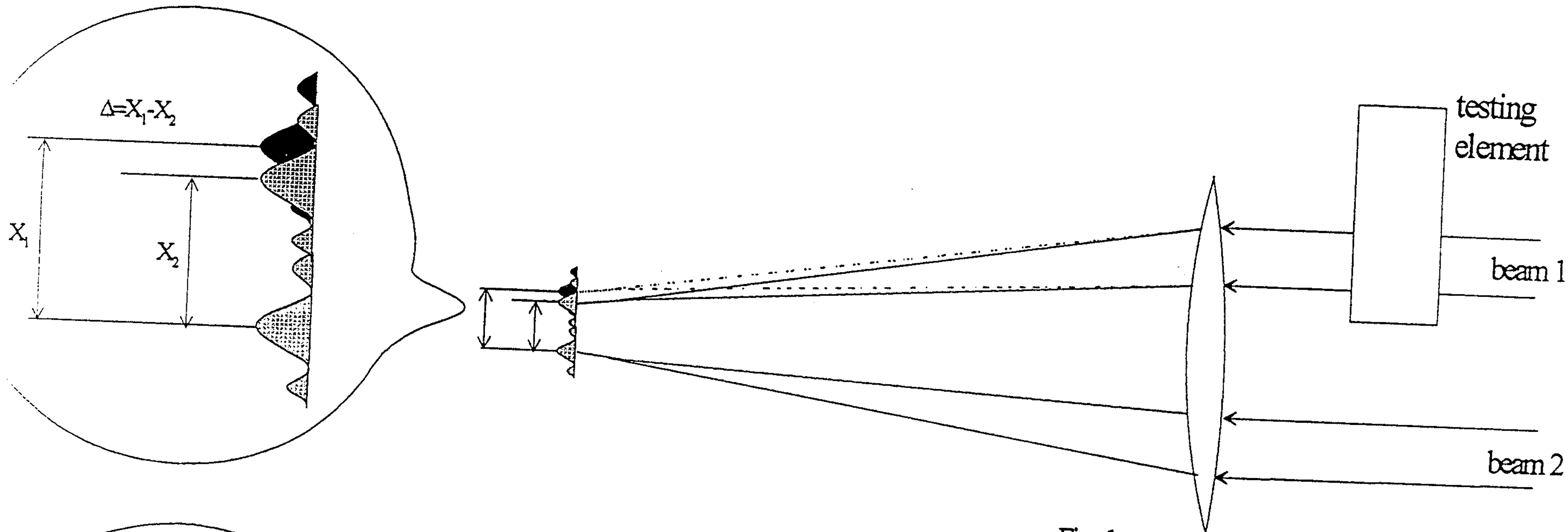
At present for measurement of wavefront distortions by optical elements apply interferometric methods and methods of comparison of laser beam parameters before and after passage of tested optical elements. The sensitivity of determination of wavefront distortions of these methods, expressed in terms of wavelengths, as a rule, makes $\lambda/20 \div \lambda/50$ (λ- probe beam wavelength). Fundamental reason of restriction of accuracy of methods is diffraction of a probe beam.

In an offered method of measurement of small wavefront distortions a method of comparison of laser beam parameters before and after passage of a tested optical element is used. The wavefront distortions by a probe laser beam in local points of a sample are measured. Then on local points wavefront distortion under the aperture of an optical element is restored.

With the purpose to increase of sensitivity of a method we offer for partial overcoming of negative action diffraction to use effect self-focusing of probe laser beam. Application of effect self-focusing will allow to compensate diffraction growth of a probe beam, as will allow essentially to increase sensitivity of determination of wavefront distortions.

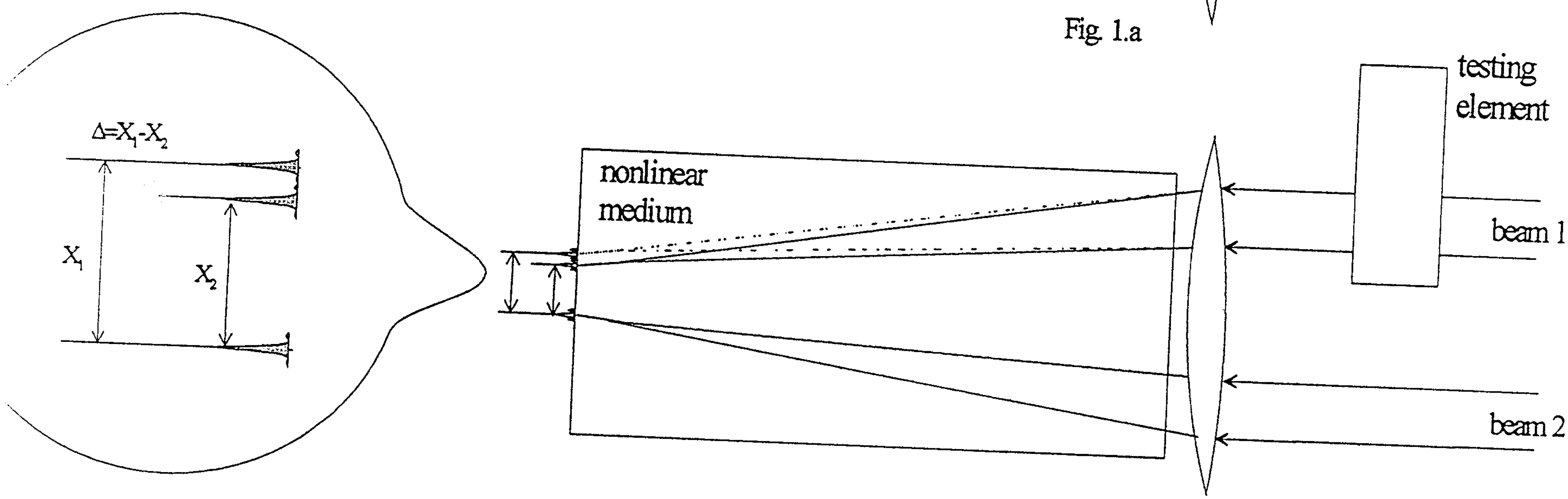
Estimation and experiments carried out by us show, that sensitivity of this method makes no less than $\lambda/600$.

At present the problem of increase the accuracy of determination of wavefront distortions becomes especially urgent. It is connected with creation of powerful laser facilities with high brightness of radiation. With the help of our method it is possible essentially to increase accuracy of definition the wavefront distortions, arising in multielement optical systems and, accepting the appropriate measures, to improve their parameters.



Δ=X1-X2
X1
X2
testing element
beam 1
beam 2

Fig. 1.a



Δ=X1-X2
X1
X2
nonlinear medium
testing element
beam 1
beam 2

Fig. 1.b

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TU3A-6

A 0.5MA VACUUM CLOSING SWITCH

S. Bower, K. Cook, R. Keyse, F. Jones

EEV Limited
Carholme Road
Lincoln, LN1 1SF

Introduction

For several decades the mercury cathode ignitron has been the most common switch choice for high voltage very high current applications. Such devices were capable of operation at voltages of typically up to 20kV and currents of 200kA providing they were carefully operated and maintained. However, in recent years the emergence of a number of specific applications with current and voltage requirements in excess of these levels, and increasing opposition to the use of mercury on environmental grounds, have defined a requirement for a switch of enhanced capability which does not use a mercury cathode. This paper outlines a program of work which has been undertaken at EEV to develop such a switch for operation at 24kV, 500kA, 130C/shot. The development progressed by the design, construction and testing of devices in a sequential manner, with design changes being made at each stage following port mortem analysis of the preceding iteration. This process has resulted in a device which has recently demonstrated operation at 24kV, 540kA, 170C/shot over a test of several hundred shots duration.

Target Specification

The target electrical specification for the development was as follows:

Operating Voltage	24kV
Peak forward current	500kA
Current reversal	10%
Charge transfer per shot	130C
Lifetime	1000 shots

Choice of Switch Technology

Three basic technologies were considered as a basis for the development. Each has advantages and disadvantages as follows:

1. Alternative liquid metal cathode
   For: Self healing cathode could be based on ignition design database.
   Against: Expected to suffer from similar voltage reliability problems as ignitrons.
   Alternative liquid metals are expensive.

2. Gas switch
   For: High current capability.
   Simple
   Against: Relatively high trigger voltage required.
   Narrow dynamic range.

3. Vacuum switch
   For: High current capability
   High voltage hold off
   Wide dynamic range.
   Against: Reasonable vacuum must be maintained throughout lifetime.

A series of preliminary tests were carried out on suitable demonstrator designs and following analysis of the results the vacuum switch was chosen as the most suitable.

Device development

Development of the device design progressed by the construction and testing of a number of devices. At each stage the devices were tested at levels of voltage and current appropriate to that particular design, and then following analysis and internal examination of the device, changes were made to the subsequent design iteration. The initial designs were ceramic-metal fully sealed devices of 2 1/2 inches diameter, increasing to 6 inches diameter as performance improved. The devices which were tested at the full final specification requirements were of 10 inches diameter.

A schematic diagram of the device is shown in Figure 1. The device comprises of a metal anode and cathode, spaced suitably apart and held in position by ceramic insulators, and a tubular trigger electrode which is positioned inside the lower ceramic insulator. The device is triggered by initiation of a discharge between the trigger and the cathode, creating vapor which expands into the anode-cathode gap and initiates conduction of current. The device design and operation is described in more detail in Ref 1.

Test results

A 10 inch diameter device of the type described in section 4 has demonstrated operation of 24kV, 540kA, 170C/shot. The switched current was derived from a 6.25mF capacitor bank which generated an almost critically damped current pulse of 0.6ms base width with approximately 10% reversal as shown in Figure 2. The stored energy was 1.8MJ, of which approximately 50kJ was dissipated in the switch, representing an average power of 160W at the shot rate used of one per 5 minutes. The device has successfully completed 500 shots to date at these levels.

Triggering of the device is achieved using a simple capacitor discharge circuit of 100nF charged to 10kV. The trigger current is approximately 1kA peak with a duration of approximately 1μs.

Conclusions

A fully sealed ceramic-metal vacuum switch has been developed which has demonstrated successful operation at levels exceeding the target requirements of 24kV, 500kA and 130C/shot. At the time of writing 500 shots have been demonstrated at 24kV, 540kA and 170C/shot at a shot rate of one per 5 minutes. The device is easy to trigger, has a wide dynamic operating range, a low average power dissipation and does not contain toxic material.

Acknowledgment

The support and assistance of Mr. K. Hewitt and Dr. M. Mead of AWE Aldermaston, and Dr. M. Savage and Mr. R. Sharpe of Sandia National Laboratories, Albuquerque, USA, is gratefully acknowledged.

Reference

1. GB Patent Application 2 304 990 A 26 March 1997.

Figure 1

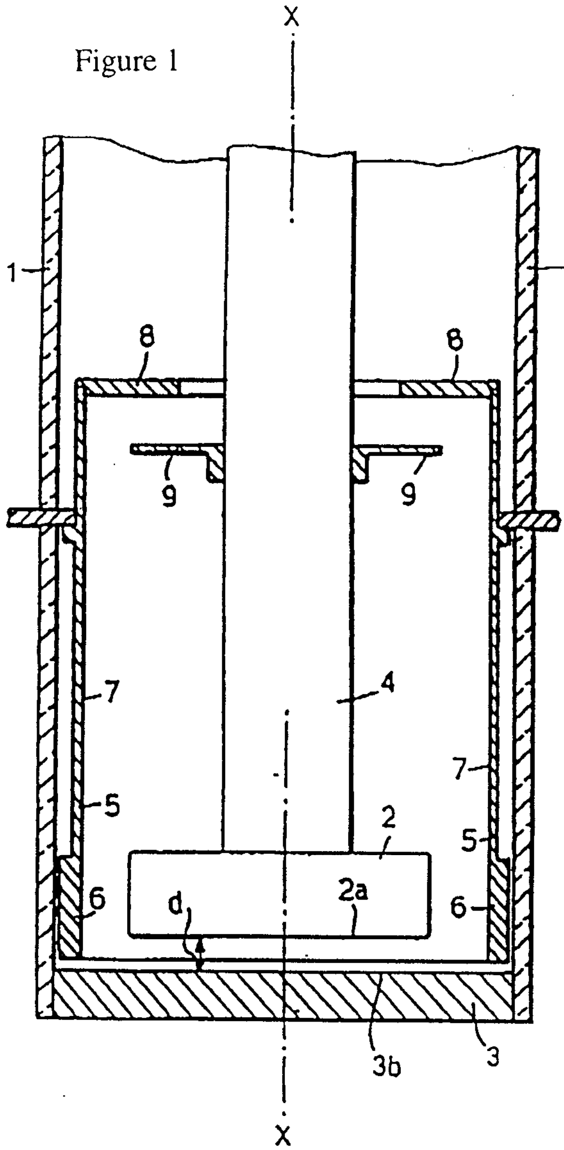
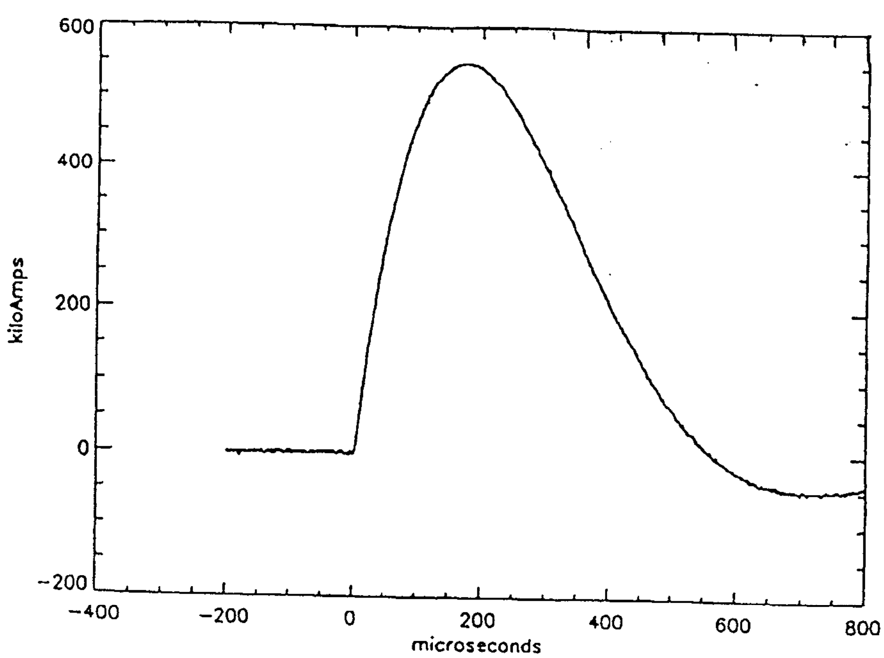


Figure 2



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TH1A-2

TOWARD A TABLE-SCALE MULTI-TERAWATT DIODE-PUMPED SOLID-STATE LASER

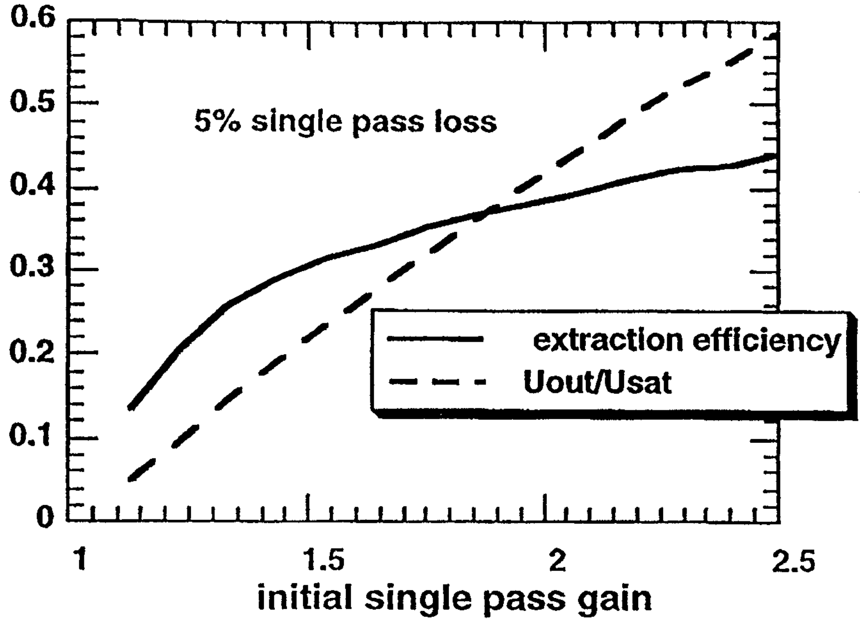
John Nees, Subrat Biswal, Akihiko Nishimura,*
Gérard Mourou, Hiroshi Takuma*

Center for Ultrafast Optical Science, University of Michigan,
2200 Bonisteel Blvd. 1006 IST, Ann Arbor, MI 48109-2099
Phone (734) 763-4875 Fax (734) 763-4876
E-mail nees@umich.edu

*Japan Atomic Energy Research Institute, 2-4 Shirane,
Tokai-mura, Naka-gun, Ibaraki-ken 319-11, Japan

Future plans for inertial confinement fusion (ICF) involve the development of megajoule lasers operating with nanosecond pulse duration, driven by a diode-pumped solid-state laser. Yb:S-FAP has excellent mechanical and optical properties for generation of the ns to picosecond pulses which are useful in driving the fusion process, but, it lacks the bandwidth necessary to generate extremely high intensities using shorter pulses. As a result it will be difficult to do experiments which require only high peak power, but do not require sustained optical flux. Many of the physical effects involved in the fusion process could be studied if a multi-terawatt solid-state laser were made on a smaller scale. This is possible with chirped pulse amplification, using a Yb-doped host material with broader bandwidth. Yb:glasses offer bandwidth ten times broader than their crystalline counterparts. They can be pumped in the same band as Yb:S-FAP to produce light in the same emission band.

At 1.03 μm wavelength this material doped at 15% Yb_2O_3 by wt. has an energy storage capability of more than 300 J/cc. This high storage density comes at the price of high saturation fluence. At the same wavelength the saturation fluence is 70 J/cm^2. Though the optical damage threshold of this material in the nanosecond range has not been tested it is expected that a clean sample would undergo surface damage near 20 J/cm^2. This dictates that efficient extraction of energy from this material cannot be accomplished in a single pass. However, by reducing the amount of energy stored in the Yb:glass to establish a low signal gain many passes may be used to extract that energy. Thus, the stored energy may be extracted at fluences well below damage threshold using 1- to 2-ns pulses. In Figure 1 the efficiency of a regenerative amplifier is plotted as a function of the small signal gain for per-pass losses of 5% respectively. The dotted line shows the fraction of saturation fluence obtained in the output pulse.



Chirped-pulse amplification has been demonstrated up to 14J/cm^2 in Yb:silicate fiber using a Ti:sapphire pump laser and in Yb:phosphate glass up to 7 J/cm^2 using a flashlamp-pumped Ti:Sapphire laser. The latter result produced 8 mJ with an 15 nm bandwidth and nearly 10% efficiency. The same regenerative amplifier can be directly scaled to produce a joule of output energy and 15 nm of bandwidth using a free-running flashlamp-pumped laser with more than 5 J of pump energy. Simulating laser-diode irradiation of the Yb:glass in this way the generation of pulses with sufficient energy and bandwidth to form 10 TW peak power. Preliminary results show a free running laser operating with greater than 50% slope efficiency with respect to absorbed pump light and delivering 1.5 J output in free-running mode. Broadband regenerative amplification has been demonstrated above 100 mJ. Limitations for scaling over 1 PW will be discussed.

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MP

A HIGH ENERGY LASER SYSTEM FOR HIF RESEARCH AT GSI

M. Roth, M. Geissel, W. Süß, D.H.H. Hoffmann and W. Seelig
Darmstadt University of Technology, D-64289 Darmstadt, Germany

C. Stöckl
University of Rochester, Rochester, NY, 14627, USA

M.D. Perry
Lawrence Livermore National Laboratory, Livermore, CA 94550, USA

R. Bock
Gesellschaft für Schwerionenforschung, Darmstadt, Germany

For the development of a heavy ion driven inertial confinement fusion scenario a detailed knowledge of the interaction processes of the ions with the converter material is crucial. As this converter will be predominantly in the plasma state one of the main topics of the plasma physics group at Gesellschaft für Schwerionenforschung (GSI) is the interaction of heavy ions with dense hot plasma. Based on the latest results on interaction experiments with laser generated plasma targets and concerning the high current upgrade of GSI a new high energy laser system is proposed. It will serve as a driver for interaction experiments with heavy ions as well as a diagnostic tool for heavy ion generated plasmas. In addition, with the combination of high current heavy ion beams and intense lasers innovative, fundamental research in the field of high energy density physics will be accessible for the first time.